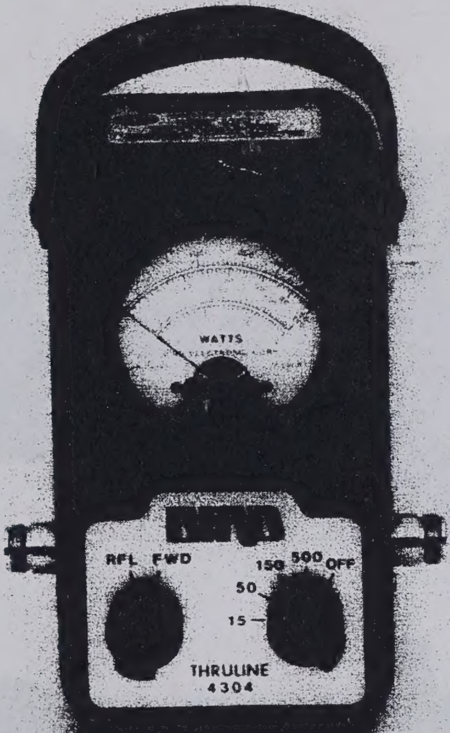
INSTRUCTION BOOK

RF Directional
multi-range dual mode
Thruline® Wattmeter

Model 4304



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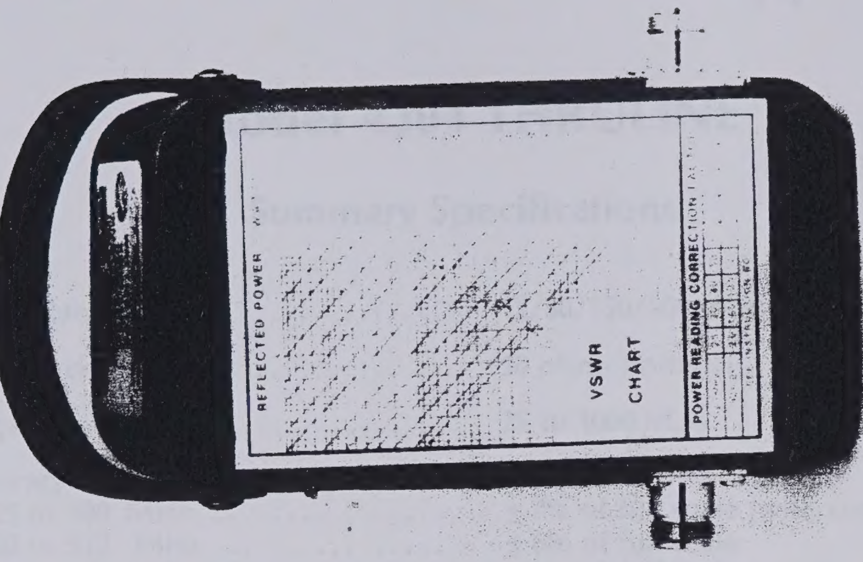
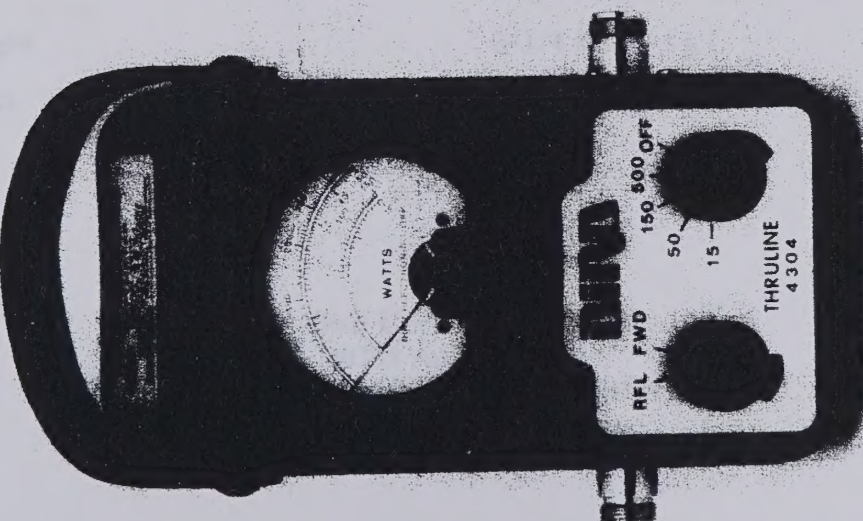

REFLECTED POWER
VSWR
CHART
POWER READING CORRECTION FACTOR

RF
SAMPLE


WATTS
RFL FWD
15
50
150
500
OFF
THRULINE
4304

Model 4304 THRULINE

Summary Specifications

Power Ranges (4)	15/50/150/500 Watts
Impedance	50 ohms nominal
Frequency Range	25 to 1000 MHz
Accuracy	
25 to 100 MHz	± 7% of full scale (with curve)
100 to 512 MHz	± 6% of full scale
512 to 1000 MHz	± 7% of full scale
RF Coupling (Sample port)	–43dB ±5dB
Insertion VSWR	1.05 max., 25 to 512 MHz 1.10 max., 512 to 850 MHz 1.15 max., 850 to 1000 MHz
Insertion Loss	0.1dB max.
Connectors	Bird Small Quick Change "SQC" type Female UHF (normally supplied)
Dimensions	Height 7" (178mm) Width (without connectors) 3-53/64" (97.2mm) Width (with F N connectors) 5-17/64" (133.7mm) Depth 3-11/16" (93.7mm)
Weight	2-1/4 lbs. (1 kg.)
Finish	Blue epoxy/polyester

Bird Electronic Corp.
30303 Aurora Road
Cleveland (Solon), Ohio 44139

SECTION I

General Description

The Model 4304 Thruline® is a portable, multi-range RF Wattmeter (VSWR indicator). It is a rugged device which requires no external power source or batteries for operation. It is used to measure RF power [illegible] in any 50 or 52 ohm transmission line. When operated in this manner, it is used to determine power flow and load match in coaxial transmission lines. It may be used to "make" measurements of CW, AM, FM and TV transmitter envelopes, but not for measuring pulsed transmitters.

There are four power ranges which are controlled by a selector switch on the front face of the unit. Each position of the selector switch corresponds to a power range on the readout meter. See Summary Specifications, Page iv. A selector switch on the front panel selects forward or reflected power. These

An additional feature of the Model 4304 is an RF sampling output for frequency analysis on a scope, spectrum analyzer or frequency counter.

The sampling signal is continuously available from a BNC type output jack located on the upper side face of the unit above the output connector. The output signal of the jack is [illegible] below the main signal level, see Summary Specifications, Page iv.

The meter, line section and related circuitry of the instrument are contained in a rugged aluminum housing. The housing is equipped with a leather carrying strap. Four rubber bumpers are on the bottom and four rubber bumper feet on the back face. These bumpers will allow the unit to be used in a standing (vertical) or flat (horizontal) position.

SECTION I

General Description

The Model 4304 Thruline® is a portable multi-range RF Wattmeter VSWR indicator. It is a rugged device which requires no external power source or batteries for operation. It is used to measure RF power when inserted into any 50 or 52 ohm transmission line. When operated in this manner, it is used to determine power flow and load mismatch in coaxial transmission lines. It may be used to make measurements of CW, AM, FM and TV modulation envelopes, but not for operation with pulsed transmitters.

There are four power ranges which are controlled by a selector switch on the front face of the unit. Each position of the selector switch corresponds to a power range on the read-out meter, see Summary Specifications. Another selector switch on the front panel selects forward or reflected power mode.

An additional feature of the Model 4304 is an RF sampling output for frequency analysis on a scope, spectrum analyzer or frequency counter.

The sampling signal is continuously available from a BNC type output jack located on the upper side face of the unit above the output connector. The output signal of this jack is 43dB ±5dB below the main signal level, see Summary Specifications, Page "A".

The meter, line section and related circuitry of the instrument is contained in a rugged aluminum housing. This housing is equipped with a leather carrying strap, four rubber bumper feet on the bottom and four rubber bumper feet on the back face. These bumper feet allow the unit to be used in a standing (vertical) or flat (horizontal) position.

SECTION II

Theory of Operation

Traveling wave concept - The operation of the Model 4304 Wattmeter is based on the traveling wave concept of RF transmission. As RF power is applied to a transmission line, there is a forward wave traveling from the transmitter to the load, and a reflected wave traveling from the load to the transmitter. The closer the load is attached to the line, the smaller the reflected wave will be. To determine the watts dissipated in the loading, it is necessary to determine the power of the forward wave and the power of the reflected wave. The difference between the two will indicate effective power dissipation.

Traveling wave vs Standing wave - The interference between forward and reflective waves, produces a standing wave in a coaxial system. In the standing wave concept, VSWR (voltage standing wave ratio) is a widely used implement. There is a simple relationship between forward power, reflected power and VSWR.

Example: $$\text{VSWR} = \frac{1 + \sqrt{\dfrac{\overset{R}{W}}{\overset{F}{W}}}}{1 - \sqrt{\dfrac{\overset{R}{W}}{\overset{F}{W}}}}$$

where $\overset{F}{W}$ = forward power; and $\overset{R}{W}$ = reflected power

Since there is a definite relationship between standing wave ratio and the forward-reflected power ratio, the forward and reflected powers may be read, as indicated by the Thruline meter, and conveniently converted to VSWR. The charts furnished in this Instruction Book or the VSWR Graph on the unit may be used for this purpose.

Coupling Circuit - When the Wattmeter is connected into the system, the RF power is directed through the metered line section, which is a short uniform section of 50 ohm air line which will not impair the impedance of the RF coaxial line into which it is inserted. There are coupling circuits in the line section, and RF waves traveling through the line section produce energy in these coupling circuits by inductance and capacitance. The inductive currents will flow according to the traveling waves producing them. The capacitive portion of these currents is independent of the traveling waves. It is therefore apparent that the current produced from the waves traveling in one direction will add in phase, while the current produced from the waves traveling in the opposite direction will subtract in phase.

The forward coupling circuit is so designed that the wave components traveling in the opposite direction will cancel each other out almost completely, making the coupling circuit highly insensitive to the reverse wave direction. Because of the highly directional characteristics of the coupling circuit, the resultant direct current which is sensed by the microammeter, indicates the power level of only the RF waves traveling in the forward direction.

Reflected Power Readings - A coupling circuit, identical to the forward power coupling circuit, is used for the reflected power reading. This circuit is positioned so that it will sense the power in the direction opposite to the forward direction. The meter will indicate this power when the mode switch is placed in the RFL position. The energy resulting from the inductively coupled component of the forward wave will bring about cancellation as described above.

Sampling Circuit - A coupling circuit similar to the forward and reflected sensors is used in the RF sampling circuit. This circuit however, delivers an unrectified, attenuated signal to the BNC type RF sample jack located on the side of the meter housing just above the output port.

SECTION III

Installation

The Model 4304 is a portable instrument, and the housing is not designed for fixed mounting. A leather strap is provided for carrying purposes. When transporting the Model 4304 Thruline, the range switch should be in the OFF position. This shunts the meter movement and protects it by dampening the pointer action during handling or shipping.

Be sure the power source is turned off and there is no RF power present in the coaxial transmission line before installation. Insert the Model 4304 Thruline in coaxial transmission lines of 50 ohms nominal impedance. Attachment is made through the connectors on either side of the wattmeter housing. A short length of 50 ohm cable fitted with the appropriate mating connectors may be useful when inserting the wattmeter in the transmission line. The input side of the unit i.e., connector labeled "Input" must be connected to the transmitter side of the coaxial transmission line and the "Output" side to the dummy load or antenna. If coaxial cables other than 50 ohm impedance are used, a mismatch will occur causing probable serious inaccuracies in readings. We urge that this condition be avoided if possible.

The Model 4304 is normally supplied with two Female UHF type connectors which are of the Bird Small Quick-Change design. Other "SQC" connectors are available, to facilitate connection to the users system. Other connectors may be obtained from Bird Electronic Corp. as required. See Section VI, Parts List.

These connectors are quickly changed by removing the four #6-32 round head machine screws from the corners of the connector flange, and pulling straight out. To install connectors, reverse the procedure making sure the center contact pin aligns properly with the socket.

CAUTION

Do not drop the Thruline or subject it to a hard blow. The microammeter is shock mounted in the wattmeter housing but its delicate mechanism could be damaged by severe impact.

SECTION IV

Operation

The apparent features of the Thruline Wattmeter have been discussed in the previous sections. As previously mentioned, no batteries or external power source is required to operate the meter. A sufficient amount of power is sensed from the transmission line into which the unit is connected.

Before applying any RF power, check to see if the meter pointer is set at zero. If adjustment is required it is necessary to zero adjust the meter under no power conditions. Using a small screwdriver, turn the zero-adjust screw on the bezel of the meter, clockwise or counterclockwise as necessary until the pointer exactly aligns with the zero of the meter scale.

The range switch should be in the OFF position or at least in the highest power setting (500 W). This is especially true when the amount of power being applied is unknown. After the RF power is applied the range switch may be switched down so that a power indication is given in the upper one-third of the scale.

The mode switch should normally be in the FWD position and switched to the RFL position after a forward reading has been taken. In the RFL position, a more accurate reflected reading can be made by turning the range switch to a lower position. However, in this condition care must be taken not to switch the mode switch back to the forward position until the range switch is returned to its original setting as over ranging the meter will result. This practice, of course, is not possible when power less than 15 watts is being measured.

If the Model 4304 was inadvertently installed backwards in the transmission line, i.e., transmitter output to wattmeter output and wattmeter input to load, the forward and reflected power readings will be reversed. Thus on the mode switch FWD will indicate reverse power and RFL will indicate forward power. Since the line couplers are similar, acceptable power indications are given, however, the stated accuracies of the instrument cannot be guaranteed and the unit should be disconnected and installed correctly. Be sure RF power is turned off before disconnecting unit.

Where appreciable power is reflected, as with an antenna, it is necessary to subtract the reflected from the forward power to get load power. Power delivered to and dissipated in a load is given by:

$$W_L = \text{Watts into load} = W_F - W_R$$

This correction is negligible (less than 1 percent) if the load is such as to have a VSWR of 1.2 or less. Good load resistors, such as Bird TERMALINE® loads, will

give this negligible or unreadable reflected power. Correction factor; at frequencies below 100 MHz, a correction factor must be applied to the indicated reading to obtain a more precise power measurement. A correction factor table will be found on the back cover plate of the unit or refer to the correction factor graph, Figure 2, on Page 15.

VSWR Calculations - After obtaining the forward and reverse power as described above, the VSWR may be found by calculations as described in Section II, (Theory of Operation). A chart is also available on the back cover and Figure 3 on Page 18, to simplify finding VSWR. Simply apply the obtained forward and reverse power readings to the chart, following the cross lines and taking the VSWR from the nearest sloping line.

RF Sampling port - As mentioned in Section I, (General Description) the Model 4304 Wattmeter is provided with an RF Sample output port. This port at 43dB delivers a sufficient amount of output for a scope, spectrum analyzer or frequency counter. Connection should be made through a 50 ohm coaxial lead, (such as RG58 A/U) equipped with an appropriate male BNC connector.

SECTION V

Maintenance

Introduction

With the simple construction and self contained nature of the Model 4304 Thruline equipment there is only a moderate amount of maintenance required. One of the major precautions is handling, use reasonable care and do not drop the unit.

Care and cleanliness is a main factor in maintenance. If any of the contacts or line connectors become dirty, they should be cleaned with dry cleaning solvent on a cotton swab stick. (Avoid excessive skin contact or inhalation of fumes when using any dry cleaning solvent). Clean all contact surfaces and especially the exposed faces of the teflon insulators.

The meter face and the housing can be cleaned with a soft damp cloth, use a mild detergent solution.

Troubleshooting

As a brief guide to the operation in isolating occasional difficulties that may occur in the use of the Model 4304, the following summary is included. The remedies for the same are referenced in the text or are self evident.

Difficulty	Suggested Cause
No meter indication	No RF power. Open or short circuit in dc circuit. Defective meter, RF sensor or switch connections.
Intermittent or inconsistent meter readings.	Faulty load. Faulty transmission line. Bad connection or faulty solder joint. Sticky or defective meter.
High VSWR or high reflected power.	Defective load or antenna. Defective or loose connectors. Shortened or open transmission line. Foreign material in RF connector bodies.

Although the Model 4304 is designed to be rugged and give years of trouble free service, occasionally repair or replacement may become necessary. Following in this section are repair or replacement procedures. Certainly no repairs should be attempted by the user for the first year while the unit is in warranty as this may be cause to void the warranty.

If a problem should occur in the line section or coupling circuits it is advised that the unit be returned to the Company for repair and recalibration. Consult with Bird Electronic Corporation Customer Service Department.

Circuit Board Repair or Replacement

1. For access to the inside of the meter housing remove the rear cover by taking loose the four screws securing it and pulling it straight off. These screws are located near the back center of the sides, bottom and top.

2. To free the circuit board for replacement of parts, unscrew the hex nuts from the meter lugs. These lugs hold the circuit board in place. Gently lift out the circuit board being careful not to disturb or tear loose the board or switch connections of the ribbon cable.

3. If the circuit board is to be removed entirely, unsolder the ribbon cable from the circuit board. Be sure to remember the location of each wire connection for reconnection. A useful hint is to make a sketch of the connections before unsoldering.

Meter Removal

With the circuit board detached as above, unscrew the three screws and nut sets retaining the meter. The meter is now free and may be lifted out of the meter housing.

Switch Removal

Before attempting to replace the range or mode switch, the line section must be removed. This is easily done by removing the two screws located on the bottom of the unit. These screws secure the line section bracket and when removed, the line section and bracket are free from the housing except for attached wiring. Gently lift the line section out of the way, exposing the rotary switches, being careful not to break the junctions of the connecting wires.

Remove the switches by the following procedure:

1. Remove knob, loosen set screw on side of knob and pull straight off.

2. Unscrew large retaining nut under knob.

3. Remove switch from inside the housing.

4. When disconnecting and replacing wires, be sure to replace them on the correct terminals.

5. To reassemble reverse the above procedures.

Calibration

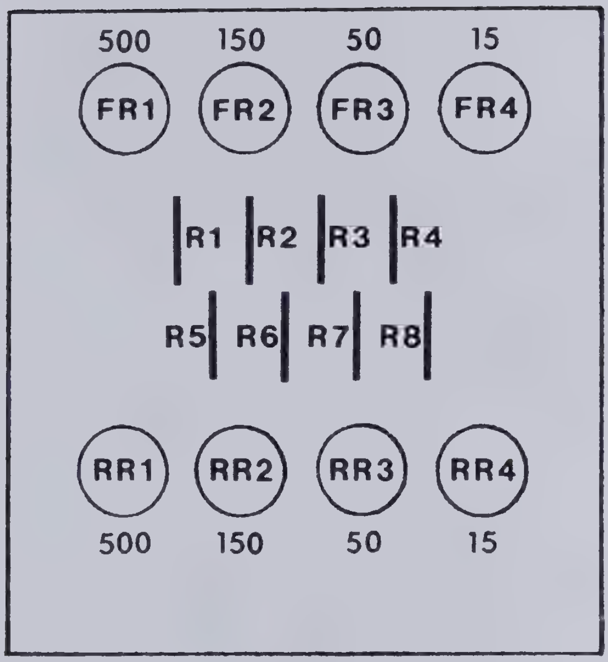
If recalibration is necessary set-up the 4304 Wattmeter in series with a standard Wattmeter with known accuracy. For example a Bird Model 43 Thruline Wattmeter could be used. A suitable low pass filter should be used between the Wattmeter and Transmitter. The set-up should be terminated in a suitable 50 ohm Load like the Bird 8201. Make all connections as short as possible to avoid mismatches and additional insertion losses.

Remove the back cover from the Model 4304 by removing the four (4) screws. This will expose the eight calibration pots. The identification of the pots and the power ranges they will adjust is shown in figure 1. Clockwise rotation of pots will increase meter reading.

Set Fwd/Rfl switch to Fwd position and set power range switch to range to be calibrated. Apply RF power of known value and frequency desired to 80% of full scale, adjust suitable calibration pot so Model 4304 agrees with standard Wattmeter. To calibrate the reflected ranges the Fwd/Rfl switch should be put in the Rfl position.

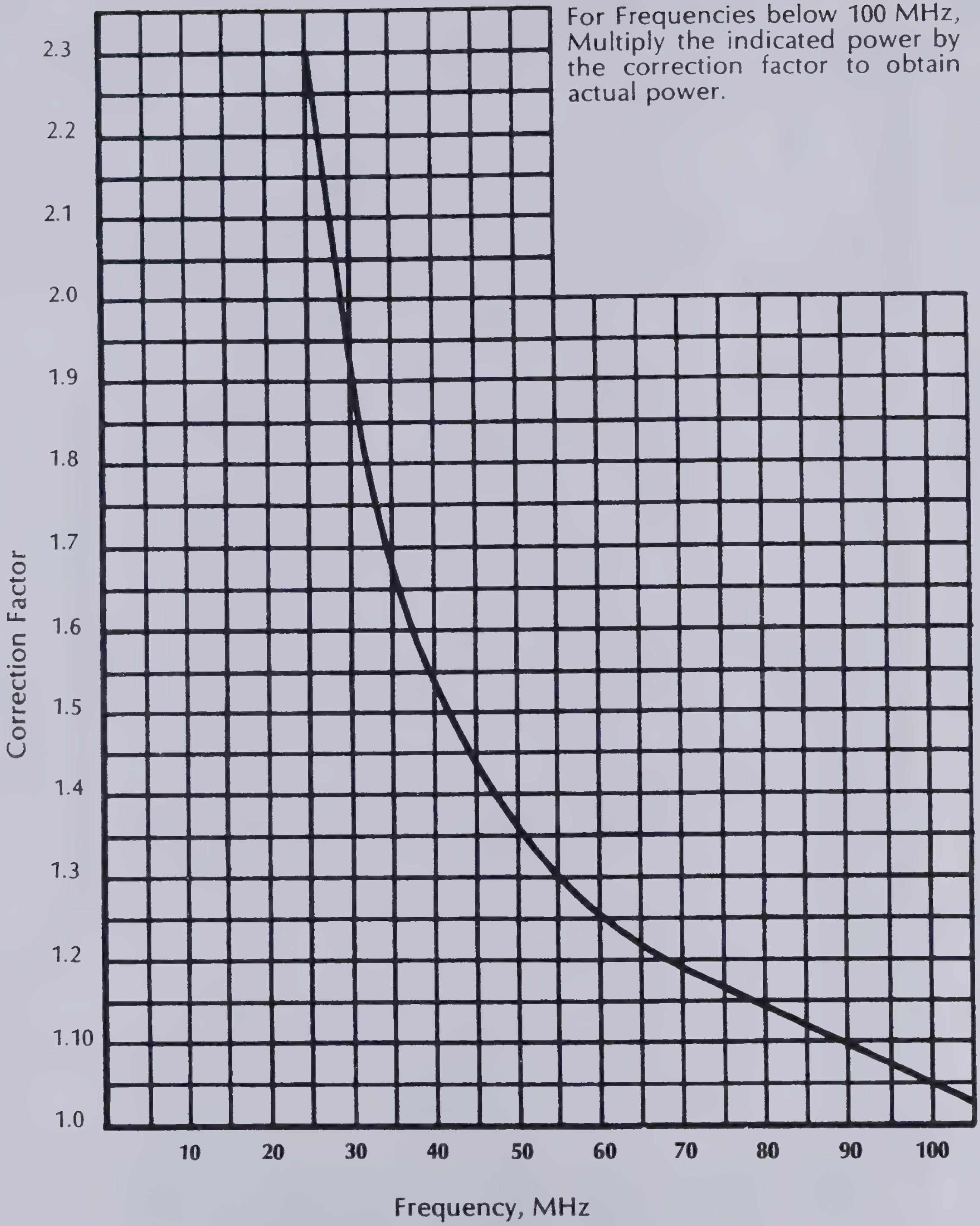
Replacement Parts List

Item	Req.	Description	Part No.
1	1	Meter	2080-051
2	3	Meter Bumpers	6254-010
3	1	Assy., P.C. Board	4304-022
4	1	RF Power Range Switch	4304-013
5	1	FWD, RFL Power Switch	4304-019
6	1	Assy., Ribbon Cable	4304-024
7	1	Assy., Coupler Plate	4304-021
8	1	Assy., Element Plate	4304-028
9	8	Bumper Feet	5-875
10	1	Carrying Strap	8580-003
11	2	Carrying Strap Spacer Screw	8240-054
12	2	10-32 x 1/2 Phillips Truss Head Screw	Std.
		("Q.C." Connectors (Type installed depends on specific order)	
13	2	Q.C. Connector - Female N	4100-014
14	2	Q.C. Connector - Female UHF	4100-017



R4, R8	2	5-1365-2	RESISTOR, 1/4W, 1.5K Ohm
R3, R7	2	5-1365-3	RESISTOR, 1/4W, 15K Ohm
R2, R6	2	5-1365-4	RESISTOR, 1/4W, 33K Ohm
R1, R5	2	5-1365-5	RESISTOR, 1/4W, 68K Ohm
RR4, FR4	2	5-1364-1	POTENTIOMETER 5K Ohm
RR3, FR3	2	5-1364-4	POTENTIOMETER, 10K Ohm
RR2, FR2	2	5-1364-2	POTENTIOMETER, 25K Ohm
RR1, FR1	2	5-1364-3	POTENTIOMETER, 50K Ohm
2	1	4391-030	HEADERS, RT. ANGLE, MOD.
1	1	4304-010	BOARD, P.C.

Figure 1



For Frequencies below 100 MHz, Multiply the indicated power by the correction factor to obtain actual power.

Figure 2

Model 4304
Frequency Calibration Chart

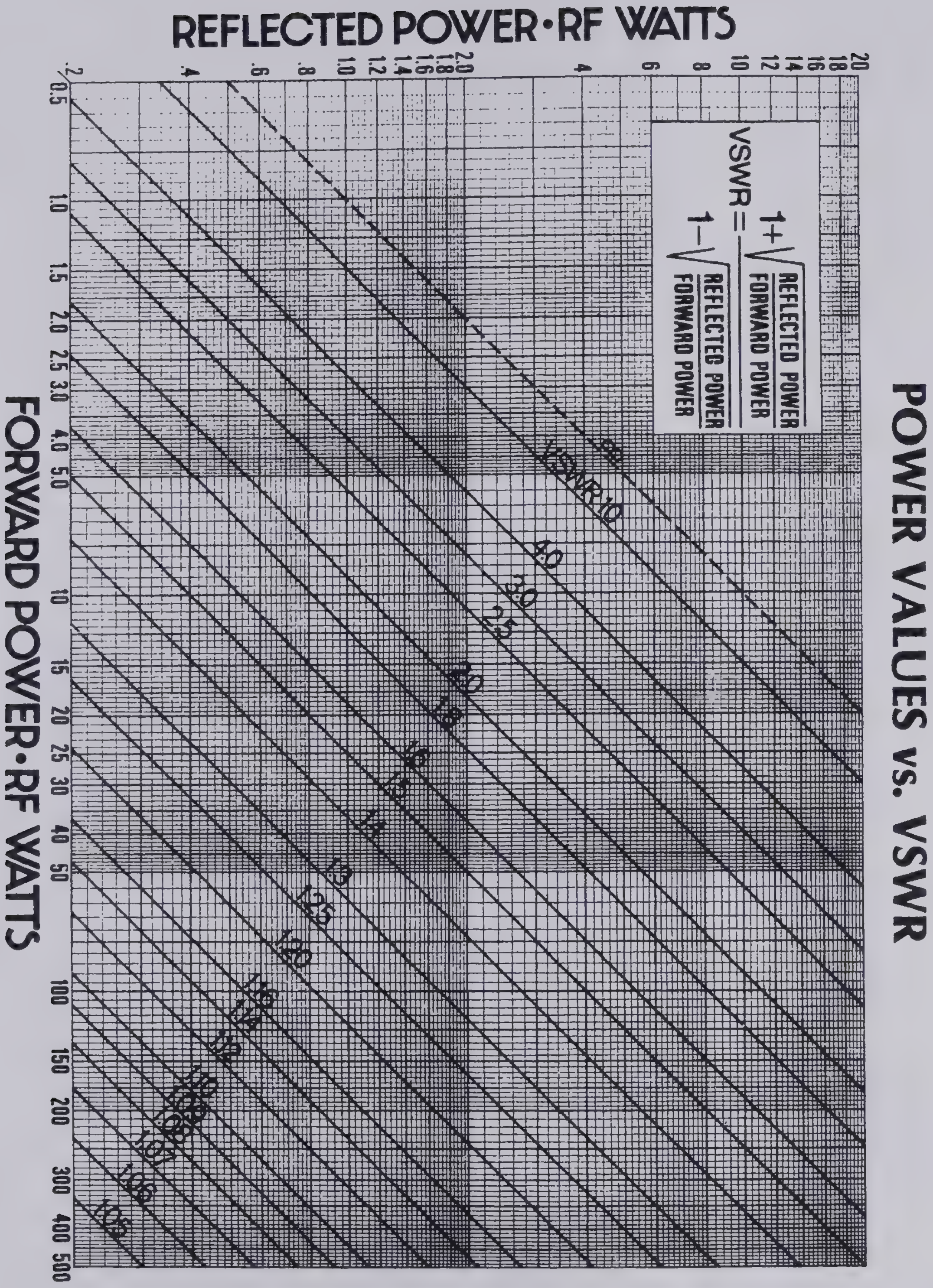

POWER VALUES vs. VSWR
REFLECTED POWER • RF WATTS
FORWARD POWER • RF WATTS
$VSWR = \frac{1+\sqrt{\frac{\text{REFLECTED POWER}}{\text{FORWARD POWER}}}}{1-\sqrt{\frac{\text{REFLECTED POWER}}{\text{FORWARD POWER}}}}$
.2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0 4 6 8 10 12 14 16 18 20
0.5 1.0 1.5 2.0 2.5 3.0 4.0 5.0 10 15 20 25 30 40 50 100 150 200 300 400 500
VSWR 10
5.0
4.0
3.0
2.5
2.0
1.8
1.6
1.5
1.4
1.3
1.25
1.20
1.16
1.14
1.12
1.10
1.09
1.08
1.07
1.06
1.05

Figure 3

BIRD

INSTRUCTION BOOK

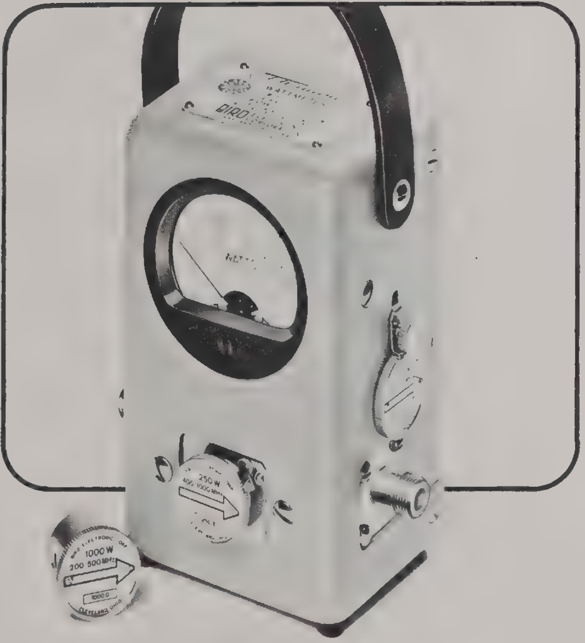
THRULINE®
RF Directional Wattmeter

model 43

INSTRUCTION BOOK

THRULINE®
RF Directional Wattmeter

model 43



BIRD

30303 Aurora Rd. Cleveland (Solon) Oh. 44139

SUMMARY SHEET

Circuit - 50-ohm impedance - THRULINE

Measures - RF Power - 5W to 5000W Full Scale Direct Reading in Watts, Frequency Range 2 - 1000 MHz in Six Std. Element types, See Table I, Section 4.

Insertion VSWR - Less than 1.05 VSWR up to 1000 MHz

Accuracy - ±5% of Full Scale Power

Dimensions - Basic Overall 7"lg x 4"w x 3"h

Weight - 4 Pounds

Connectors - Female and Male "N"
Female and Male "HN"
Female and Male "C"
Most std. 50-ohm AN types
} Not supplied on regular orders

2 Female "N" Connectors standard with equipment, unless otherwise specified.

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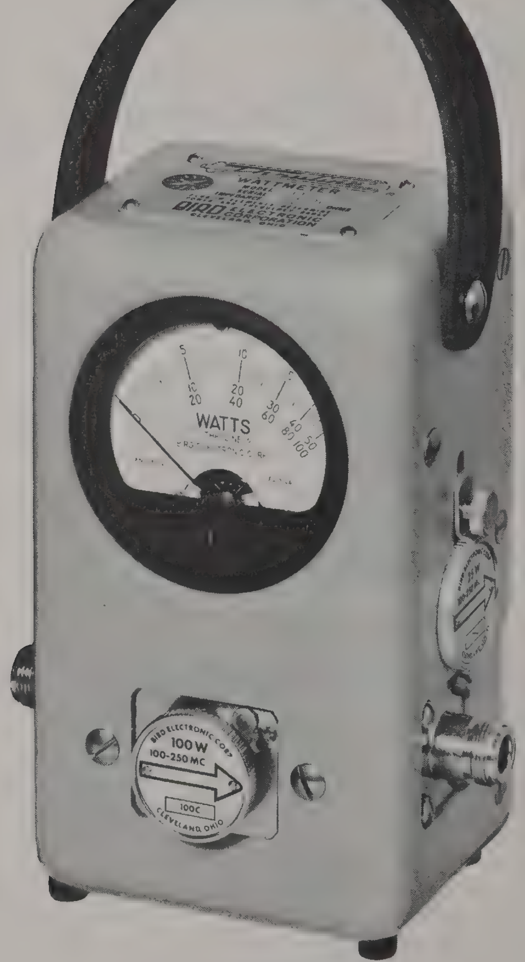


Fig. 1-1. Model 43 THRULINE

SECTION 1
GENERAL DESCRIPTION

1. PURPOSE AND APPLICATION

The Model 43 THRULINE Wattmeter is an insertion type RF wattmeter, designed to measure power flow and load match in 50-ohm coaxial transmission lines. It is intended for use on CW, AM, FM, and TV modulation envelopes, but not pulsed modes. The Model 43, when used in 50-ohm applications, has an insertion VSWR of less than 1.05:1 up to a frequency of 1000 MHz. The meter is direct reading in watts, expanded down scale for easy reading, and is graduated 25, 50, and 100 watts full scale. The power ranges used are determined by the Plug-In Elements, which fall in ten frequency band groups covering from 2 to 2300 MHz plus additional special Elements in various power and frequency ranges (see Section 4). Further characteristics may be found in the Summary Sheet on page A.

2. DESCRIPTION

The Model 43 THRULINE, Figure 1-1, is a portable unit contained in a die cast aluminum housing, with a formed metal enclosure on the back which is easily removed. Included with the unit is a leather carrying strap, four rubber shock feet on the base, and four rubber bumpers on the back, which allow the Model 43 to stand or lie flat when used. For additional protection, the microammeter is specially shock mounted. A slotted screw is provided on the lower front face of the meter for zeroing the pointer. Below the meter, the RF line section face protrudes slightly from the wattmeter housing with the Plug-In Element socket in the center.

A shielded cable connects the microammeter to the dc jack which is attached to the side of the RF line section casting. This cable, nearly three feet long, permits removal of the RF line section from the Wattmeter housing. Meter connections may be maintained with any installations outside of the housing. This permits permanent additional installations to be made. See Section 3, INSTALLATION.

Inside the dc jack assembly, there is a filter capacitor which shunts the meter circuit to prevent mis-readings caused by stray RF energy existing in the Plug-In Element. Mounted on the dc jack is a phosphor bronze spring finger, which protrudes through a lateral hole and into the Plug-In Element socket of the RF line section. The finger has a button on its end which mates with the contacts of the Plug-In Element. The nickel plated brass RF line section is precision made to provide the best possible impedance match to the coaxial RF transmission line in which the Model 43 is inserted. The ends of the line section are nested in mating slots to provide additional mechanical support.

At each end of the line section are Bird Quick-Change type RF connectors, which may be quickly interchanged with any other Bird "QC" connector by removing the four screws on the mounting flanges. The Wattmeter housing does not interfere with any connector changes.

To make measurements, the cylindrical shaped Plug-In Element is inserted into the line section socket and rotated against one stop. A small catch in the upper right hand corner of the casting face presses on the shoulder of the Plug-In Element to keep it in proper alignment and assure a good contact with the dc jack and between the lower edge of the Element and line section body. On diametrically opposite sides of the Plug-In Element body are contacts to provide dc pick-up in either direction. These contacts make connection with the spring finger of the dc jack only when the Plug-In Element is in the precise forward or reverse position, and with the index pin on the Element on the lower level of the line section casting face against its respective stop.

SECTION 2
THEORY OF OPERATION

1. TRAVELLING WAVE VIEWPOINT

The best way to visualize the THRULINE idea is from the TRAVELLING WAVE viewpoint on transmission lines, which illustrates that the voltages, currents, standing waves, etc., on any uniform line section are the result of two travelling waves:

FORWARD WAVE travels (and its power flows) from source to load, and has RF voltage E and current I in phase, with $E/I = Z_O$.

REFLECTED WAVE originates by reflection at the load, travels (and its power flows) from the load to source and also has an RF voltage $\mathcal{E}$ and current $\mathcal{I}$ in phase, with $\mathcal{E}/\mathcal{I} = Z_o$.

Note that each component wave is mathematically simple, and is completely described by a single figure for power, for instance:

$\overset{F}{W}$ = Watts Forward = $E^2/Z_O = I^2 Z_O = EI$

$\overset{R}{W}$ = Watts Reverse = $\mathcal{E}^2/Z_o = \mathcal{I}^2 Z_o = \mathcal{E}\mathcal{I}$

Z_O is the characteristic impedance of the uniform line, and simplifies matters by being a pure resistance, usually 50 ohms, for useful lines. The main RF circuit of the THRULINE is a short piece of uniform air type line section, whose Z_O is a very accurate 50 ohms, in which correct measurements may be made.

2. COUPLING CIRCUIT

The coupling circuit which samples the travelling waves is in the Plug-In Element. The circuitry of the Element and its relationship to the other components of the THRULINE are illustrated in the schematic diagram, Figure 2-1. Energy will be produced in the coupling circuit of the Element by both mutual inductance and capacitance from the travelling RF waves of the line section. The inductive currents will, of course, flow according to the direction of the travelling waves producing them. The capacitive portion of these currents is naturally independent of the direction of the travelling waves. Therefore, assuming that the Plug-In Element remains stationary, it is apparent that the coupling currents produced from the waves of one direction will add in phase, and those produced from waves of the opposite direction will accordingly subtract in phase. The additive or "ARROW" direction is, of course, assigned to the forward wave.

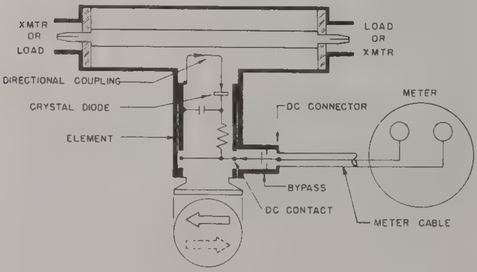


Fig. 2-1. Schematic Diagram

The electrical values of the Element circuits are carefully balanced and so designed that the current produced from the reverse wave will cancel the other almost completely. The resultant is a directivity always higher than 30 dB, which means that the Element is highly insensitive (nulled) to the "REVERSE" direction wave. Being highly directional, the THRULINE Element is sensitive (at one setting) only to one of the travelling waves which produces standing waves by interference. THRULINE measurements are therefore independent of position along standing waves. It may be said that the THRULINE doesn't know, doesn't care, and doesn't need to care where it is along a standing wave.

3. STANDING WAVE RATIO vs. REFLECTED/FORWARD POWER RATIO

As mentioned above, the THRULINE technique uses the TRAVELLING WAVE viewpoint to measure most of the outstanding facts about transmission line operation. Another widely used and related viewpoint, is the STANDING WAVE, which is quite elaborately developed both mathematically and in existing equipment. This technique can be traced to the early development of slotted lines as tools of exploration.

The slotted line is a standing wave instrument, and emphasizes this viewpoint. However, the slotted line is too long, too expensive if good, not portable, and slow in operation. These objections increase rapidly as the frequency drops below 1000 MHz. Whereas the THRULINE is surprisingly quick, convenient, and accurate by comparison. With the exception of phase angle reflection (distance, load to minimum) it tells everything a slotted line will.

The relationships between TRAVELLING WAVES and STANDING WAVE viewpoints are given in most high frequency textbooks.

SECTION 3
INSTALLATION

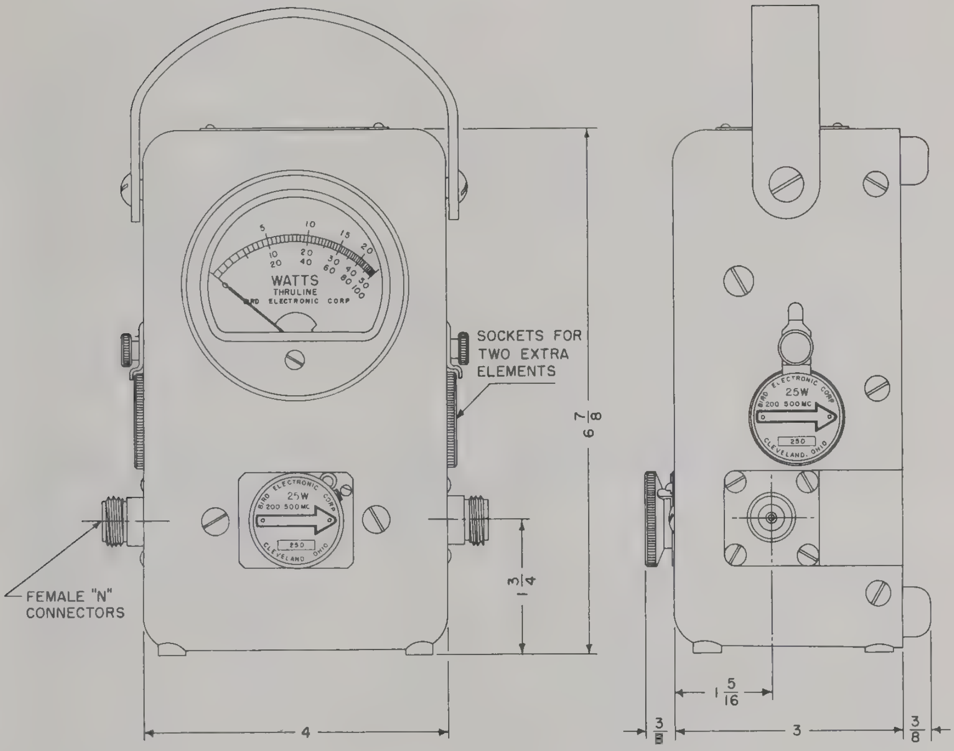


Fig. 3-1. Outline Drawing, Model 43 THRULINE

1. PORTABILITY

The Model 43 is a portable instrument, and the housing is not designed for fixed mounting (see Outline Drawing, Figure 3-1). A strap is provided for carrying purposes.

While transporting the THRULINE, it is best to insert a Plug-In Element, secure with the catch, and point the ARROW upwards. This will shunt the meter circuit and serve to protect the meter by dampening needle action during handling or shipping. Also, secure the spare Plug-In Elements in their receptacles with the thumbscrew and clamp. Handle the Plug-In Elements with care at all times. Calibration could be disturbed if they are dropped.

CAUTION

Do not drop the THRULINE or its Elements or subject them to hard blows. The microammeter is shock mounted in the wattmeter housing, but its delicate mechanism may be damaged by severe impact.

2. CONNECTIONS

Insert the Model 43 THRULINE in coaxial transmission lines of 50 ohms nominal impedance. It is indifferent to which respective side the power source and the load connections are made. If cables other than 50 ohms are used, a mismatch will occur causing probable serious inaccuracies in readings. However, if a mismatch cannot be avoided, the results may be calculated per paragraph 7 of Section 4. We strongly urge that you avoid this condition.

The Model 43 is normally supplied with two Female N-Type connectors which are of the Bird Quick-Change design. Other "QC" connectors are available as listed:

Male N
Female HN
Male HN
Female C
Male C
Female UHF
Male UHF
7/8" EIA Air Line
Female BNC
Male BNC
Female LC
Male LC
Female LT
Male LT
Female TNC
Male TNC

These may be purchased from Bird Electronic Corp., as required. See Section 6, Parts List.

The above connectors are quickly changed by removing the four #8-32 round head machine screws from the corners of the connector flange, and pull straight out. Reverse this procedure to attach connector, making sure the center contact pin aligns properly with the socket.

3. REMOTE INSTALLATION

The RF line section can be removed from the meter housing for remote installation. To remove the line section from its housing:

a. Unscrew the six #8-32 flat head machine screws holding the back cover.

b. Grasp the cover by the side filler tabs and pull directly backwards. The back cover assembly will come off with the speed nuts remaining attached.

c. Remove the two #10-32 oval head machine screws on the front of the housing.

d. Slide the line section backwards out of the housing. Do not loosen the two oval head screws on the sides of the housing in line with the meter. These hold the meter supporting shock ring in place.

e. Substitute the cable which attaches the line section to the meter with a sufficient length of cable to make the remote installation.

f. To replace the RF line section, reverse the above procedure.

It may be desirable to have two or more line sections permanently installed in continuous operating equipment. In this case, one set of Elements and one meter may be used to measure several RF transmission lines WITHOUT INTERRUPTION OF RF LINES for insertion of the THRULINE. Additional RF line sections (Figure 3-2) are available.

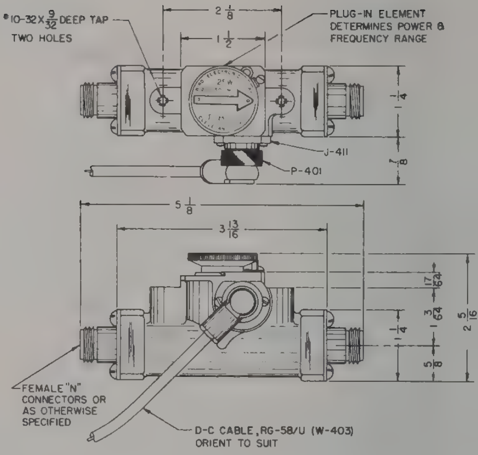

*10-32 X 9/32 DEEP TAP
TWO HOLES
2 1/8
1 1/2
PLUG-IN ELEMENT DETERMINES POWER & FREQUENCY RANGE
1 1/4
7/8
J-411
P-401
5 1/8
3 13/16
17/64
1 3/64
2 5/16
1 1/4
5/8
FEMALE "N" CONNECTORS OR AS OTHERWISE SPECIFIED
D-C CABLE, RG-58/U (W-403) ORIENT TO SUIT

Fig. 3-2. Installation Drawing, RF Line Section

The RF Line Section of the Model 43 blends very readily to panel type mounting. A layout for the panel mount cut is given in Figure 3-3. The thickness of the panel should be about 1/4 inch. On panels less than this, build up the thickness with pads or washers to achieve a flush-face mounting. Cable connections are simplified because the RF line section may be mounted in any convenient direction. Attach the line section so that the finger catch is in the most accessible position.

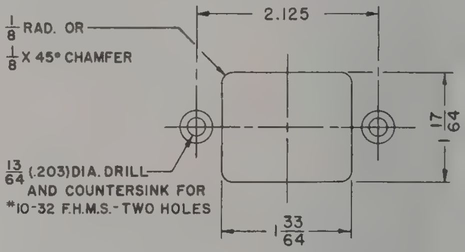

1/8 RAD. OR
1/8 X 45° CHAMFER
2.125
1 17/64
13/64 (.203) DIA. DRILL AND COUNTERSINK FOR *10-32 F.H.M.S.-TWO HOLES
1 33/64

Fig. 3-3. Panel Cut for Mounting RF Body

SECTION 4
OPERATION

1. GENERAL

The apparent features of the THRULINE equipment have been discussed in Section 1, GENERAL DESCRIPTION, and in the instructions of Section 3, INSTALLATION. Measurements are made by the insertion and operation of the Plug-In Elements previously mentioned.

The Elements determine the power range to be read on the meter scale, and the major markings (viz. 50W, 100W, etc.) are the FULL SCALE POWER value for that Element. Elements are also marked for FREQUENCY RANGE. The transmitter frequency must be within the band of the Element used. Elements are available according to those identified in the tables on page 4-6.

See paragraph 6 of this chapter for frequency band flatness, and performance of the Elements outside of stated frequencies. Elements for additional ranges (power or frequency) may be ordered without returning the THRULINE for calibration, since the RF bodies and meters are standardized, and are designed for a wide range of coaxial transmission power values and frequencies.

ARROW on Plug-In Element indicates Sensitive DIRECTION, i.e., the direction of power flow which the meter will read. ARROW and REVERSE are directional terms used in reference to the THRULINE ELEMENT, and mean respectively the sensitive and null directions of the Element. ROTATE ELEMENT to reverse the sensitive direction. FORWARD and REFLECTED are directional terms used in reference to the source - load circuit. Note that the transmitter may attach to either connector of the THRULINE. It makes no difference which external RF connection is selected, since the Elements are reversible and the RF circuit is symmetrical end for end. Before taking readings be sure that the meter pointer has been properly zeroed under no-power conditions.

The THRULINE used with a TERMALINE resistor of proper power rating forms a highly useful absorption wattmeter. With ARROW set toward the load, it is unnecessary to reverse because reflected power may be neglected.

In cases where readings are being made when the meter unit is connected to an auxiliary RF line section body, always remove any measuring Element from the unused RF line section. Otherwise, the dc circuit will be unbalanced or shorted according to the arrow position of the other Element, causing inaccurate or no reading on the meter.

2. LOAD POWER

Power delivered to (and dissipated in) a load is given by:

$$\overset{L}{W} = \text{Watts into Load} = \overset{F}{W} - \overset{R}{W}$$

i.e., where appreciable power is reflected, as with an antenna, it is necessary to subtract reflected from forward power to get load power. This correction is negligible (less than 1 percent) if the load is such as to have a VSWR of 1.2 or less. Good load resistors, such as our TERMALINES, will thus show negligible or unreadable reflected power.

VSWR scales, and their attendant controls, for setting the reference point, have been intentionally omitted from the THRULINE for two reasons:

(a) Why make something similar to a hypothetical dc volt ohmmeter with control pots for the voltmeter multipliers? Even more complications arise when diodes at RF are involved.

(b) Experience using the THRULINE on transmitter tune-up, antenna matching etc., i.e., on OPERATING PROBLEMS shows that the power ratio ϕ is no mean competitor, in practical usefulness, to the ratio ρ = VSWR.

A trial is suggested for a few days — forget VSWR and try thinking in terms of $\phi = \overset{R}{W} / \overset{F}{W}$ when the THRULINE is used. It will be noted that, even without bothering to calculate the ratio exactly, the two meter readings $\overset{R}{W}$ and $\overset{F}{W}$ give an automatic mental impression which pictures the situation. Thus, in an antenna matching problem, the main thing usually is to minimize $\overset{R}{W}$, and anything done experimentally to this end is directly indicated when the THRULINE is in the reflected position. Furthermore, the ratio of readings, only mentally evaluated, is a reliable guide to the significance of the remaining reflected power.

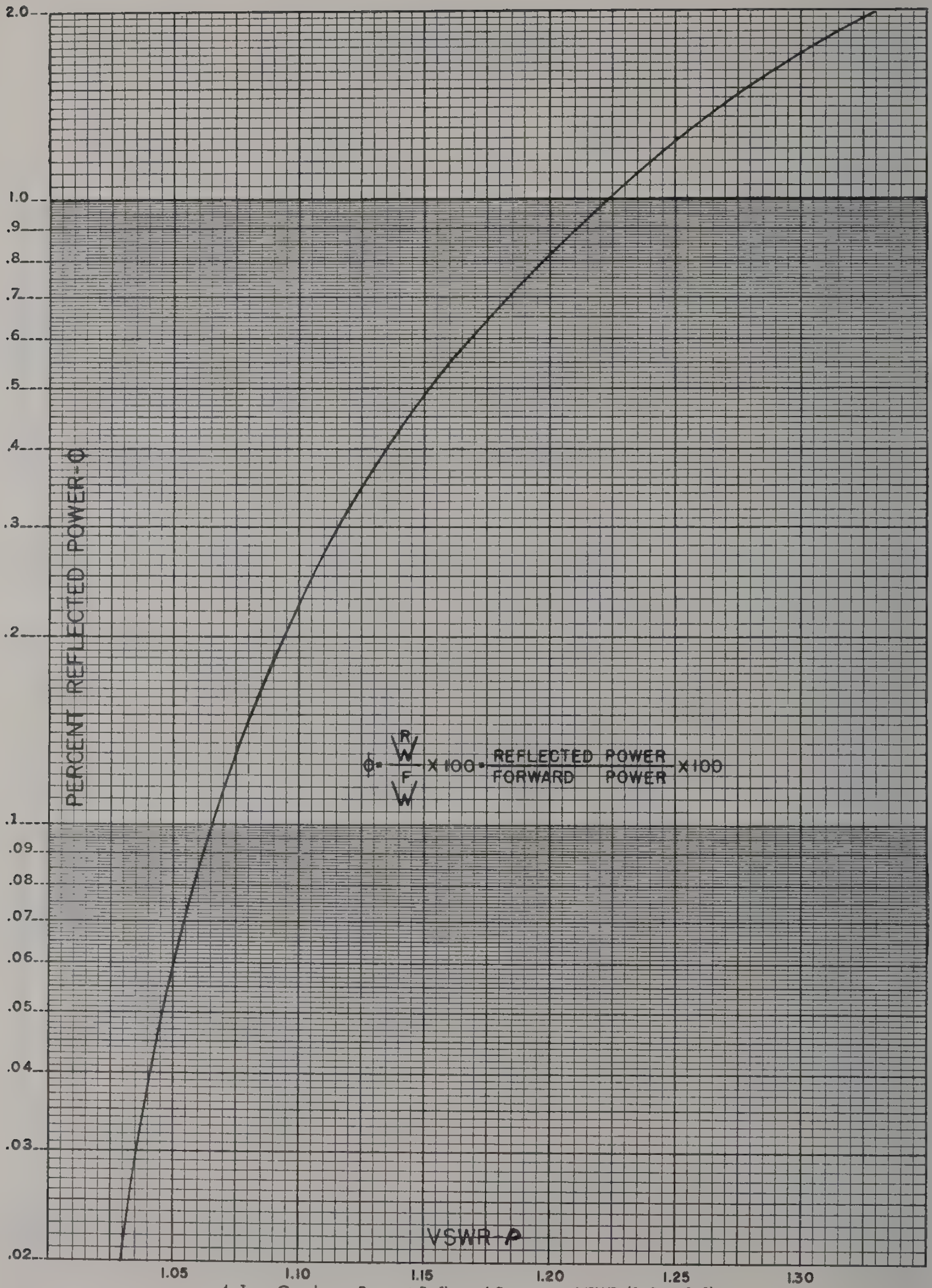
3. GRAPH—ρ VS. ϕ AND ITS SIGNIFICANCE

Since there are definite simple relationships

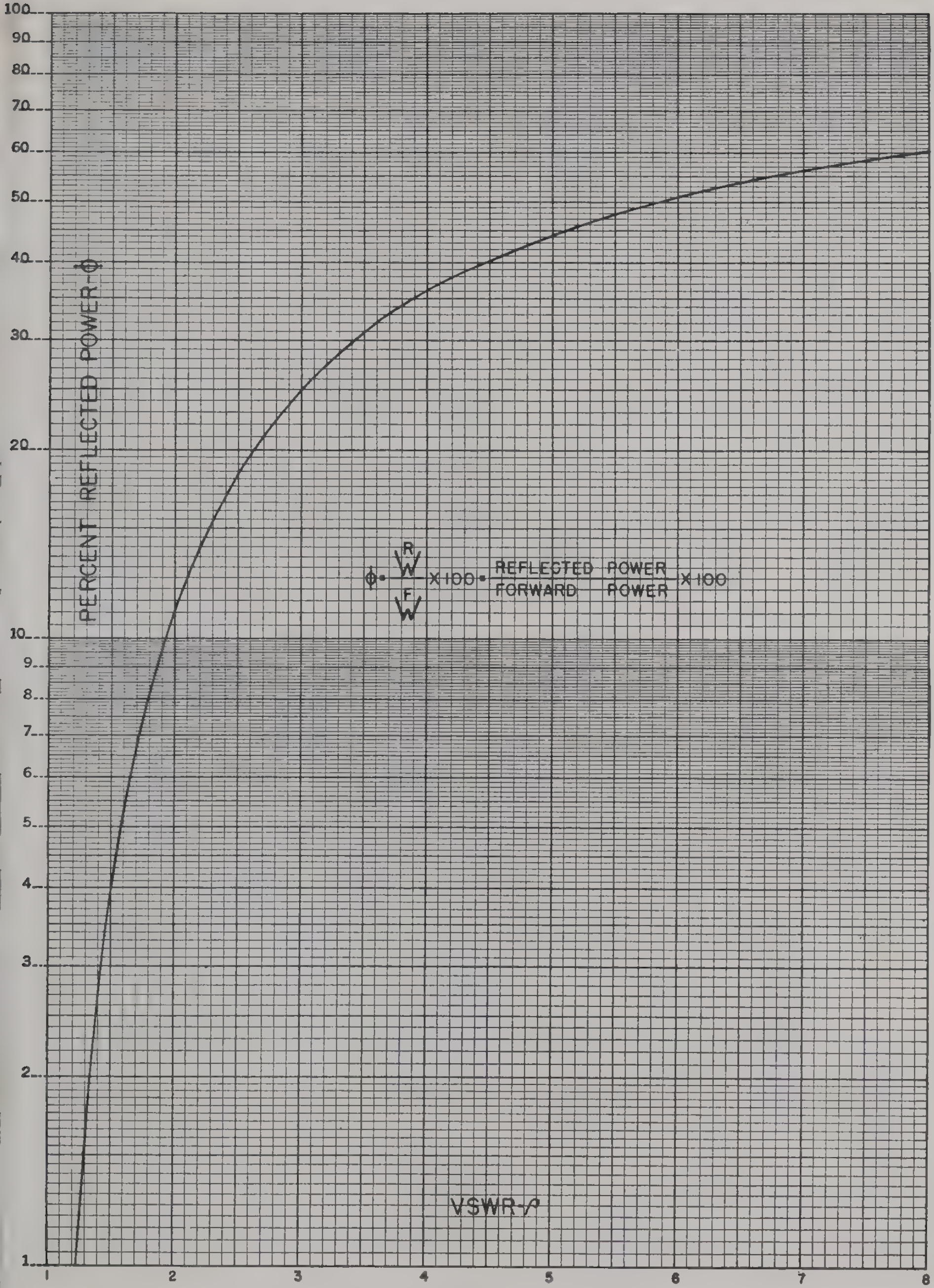
$$\rho = \frac{1+\sqrt{\phi}}{1-\sqrt{\phi}} \text{ and } \phi = \left[\frac{\rho-1}{\rho+1}\right]^2 \text{ where } \rho = \text{VSWR}$$

$$\text{and } \phi = \frac{\overset{R}{W}}{\overset{F}{W}}$$

between standing wave ratio ρ and the reflected/forward power ratio ϕ indicated by the THRULINE, the latter may be conveniently used to measure VSWR. The relationship is given in Fig. 4-1a and b.



4-1a. Graph. — Percent Reflected Power vs. VSWR (1.0 to 1.3).



4-1b. Graph. — Percent Reflected Power vs. VSWR (1.0 to 8.0).

Note, that around $\phi = 10\%$, below which $\overset{R}{W}$ will appear insignificant and become hard to read, you are close to the commonly accepted lower limit $\rho = 2$, below which improved antenna match becomes less and less worthwhile in many systems. Experimentally, using the THRULINE, it is readily shown that minimizing ϕ below 10% produces little gain in $\overset{L}{W}$. TV transmitter antenna lines, and VHF Omnirange transmitters, are among systems requiring much lower levels of reflected power for reasons other than simple power transmission. Note also in Fig. 4-1a, the very small level of reflected power, $\phi = .06$ percent, corresponding to $\rho = 1.05$. With a single Element, detection of reflected power is possible down to about $\phi = 1$ percent, $\rho = 1.2$; if $\overset{F}{W}$ approaches full scale, measurement is possible down to about $\phi = 5$ percent, $\rho = 1.5$.

LOW-REFLECTION MEASUREMENTS may be extended below this with two Elements. Say 80 watts are available, and you have 100 watt and 10 watt Elements.

Measure $\overset{F}{W}$ with the 100 watt Element. Remove 100 W Element and insert 10 watt Element.

CAUTION: 10 watt Element must be ONLY in the REFLECTED direction. ARROW toward TRANSMITTER. Insert and remove ONLY this way.

Now read $\overset{R}{W}$ on the 10 watt Element.

SPECIAL NOTE

DON'T ROTATE 10 watt Element while TRANSMITTER is on. Always use great care with LOW SCALE Elements on HIGH power RF lines. Inadvertent exposure of these Elements to too much FORWARD or even too high reflected power may permanently damage the measuring Element or the microammeter.

In this case, measurement down to at least .5 watt reflected is possible which means to

$$\phi = \frac{.5}{80}, \text{ say .6 percent, or to about } \rho = 1.16$$

and detection of reflections is possible down to about .1 watt,

$$\phi = \frac{.1}{80} = .00125, \text{ say .1 percent, or to about } \rho = 1.06$$

Caution is necessary in the above method, and preferably it should not be used with Element ranges differing more than 100 to 10, although 250 to 10 can be used with extreme caution. With certain Elements now available down to 1 watt full scale this method is usable with medium and low power transmitters.

4. MEASUREMENT & MONITORING OF TRANSMITTER POWER

Little more need be said about this, in view of LOAD POWER paragraph above. The THRULINE is useful for continuous monitoring of transmitter output, and may be found useful in continuous monitoring of reflected power, for instance in checking intermittent antenna or line faults.

Like diode devices generally, the THRULINE indicates the carrier component on amplitude modulation, with very little response to sideband components added by modulation.

5. TESTING OF LINES, CONNECTORS, FILTERS, ETC.

The THRULINE is highly useful for this purpose, and may be employed in several ways.

(a) VSWR (Insertion) or ϕ (Insertion) may be measured with the line terminated in a good load resistor (TERMALINE). The lower limits of sensitivity in this are given above under LOW REFLECTION MEASUREMENTS.

(b) ATTENUATION (Power lost by heat in the line) as well as VSWR (Insertion) and ϕ (Insertion) may be measured by inserting the unknown line between two THRULINES, or between two RF bodies used with one meter and one set of Elements. (End of line to be terminated in a load resistor). This method applies also to insertion between the THRULINE and a TERMALINE absorption wattmeter.

Very small values of attenuation require allowance for normal instrument errors. The correction may be determined by direct rigid connection of the THRULINES, or of the THRULINE-TERMALINE combination, in cascade. Slight juggling of zero settings is permissible for convenience in eliminating computation, provided readings are being taken fairly well up on scale.

(c) ATTENUATION BY OPEN OR SHORT CIRCUIT METHOD. Neater by far than method (b) is one depending on the high directivity (null balance) to which the THRULINE Elements are held. They should, and do, exhibit good equality between forward and reflected readings when the load connector is open or short circuited. In this condition $\phi = 100$ percent, the forward and reflected waves being equal in magnitude, and $\rho = \infty$ Say that this is checked on open circuit, and then a length of line of unknown attenuation, also open circuited, is connected to the load connector. The ratio ϕ then shown is the attenuation in two passes along the line (down and back).

Expressed in dB, (using the equation $N_{dB} = \log \frac{\overset{F}{W}}{\overset{R}{W}}$),

the dB figure may be compared with published data for line type and length by remembering to halve N_{dB}* because twice the line length is actually being measured.

This measurement should be supplemented by one of ϕ (Insertion) as in (a) above, or at least by dc continuity and leakage checks, since the attenuation measurement alone can be in error from faults such as open or short circuits part way down the line.

---

*Or to double the line length.

Open circuit testing is somewhat to be preferred to short circuit, since the reference short (used to check equality initially) must be good, and because the initial equality is somewhat better on open than on short circuit.

Again, for quite low values of measured attenuation, it is advisable to note exact readings (or difference) on the initial equality check, and to allow for this difference.

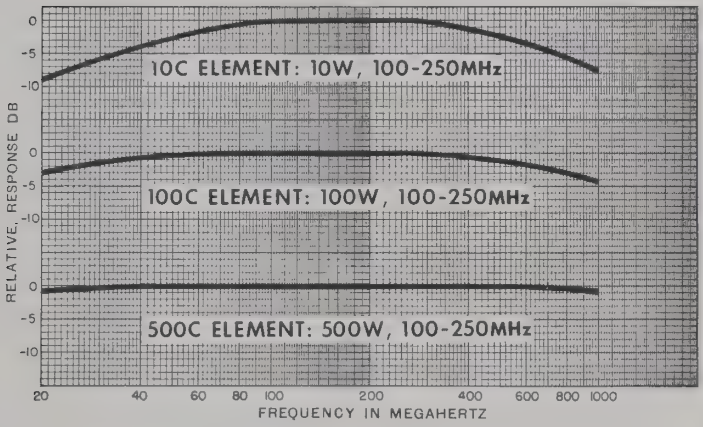
6. FREQUENCY RESPONSE

The Plug-In Elements have a very flat frequency response over a frequency ratio of more than 2-1/2 to one. This characteristic provides a practically flat response within the assigned frequency ranges for all the Elements, see Table I in this Section.

An illustrative set of curves for three Elements of one of these frequency bands is shown in Fig. 4-2. Notice that on the LOW POWER Element, the fall-off above and below the assigned frequency band is more pronounced than it is for the HIGH POWER Element. The degree of drop in response varies progressively less for each power level from low to high, with the average difference at approximately the mean power level. These curves, Fig. 4-2, may be assumed to be about typical for all of the listed band types (H, A, B, C, D & E) at their respective stated frequencies.

Harmonics, or sub-harmonics, may be known to exist in the measured circuit (outside of the Element frequency band). If so, a rough approximation of the response of the Element to these harmonics may be made by the use of these curves. The frequency ordinate to be read on the graph will be obtained by proportioning the frequency of the Element used with that of the one illustrated. Interpolation of the curve values will give an approximation of the extent that these harmonic signals are being measured by your Element.

The use of the Elements for direct power measurements outside of their stated frequency range is not recommended.



FREQUENCY RESPONSE
THRULINE ELEMENTS
100-250 MHz (C-Series)

Fig. 4-2. Graph — Representative Frequency Response

7. IMPEDANCE MISMATCH

There may be cases where it is necessary to use the THRULINE on other than the 50-ohm circuit for which it is designed.

Using the THRULINE, you will be inserting a 4-inch length of 50-ohm air line and the load on the transmitter will be changed from its original condition without the THRULINE. For a power reflection factor under 10% and frequency below 200 MHz, the 4-inch length mismatch is not too serious. But going any higher than these values, even if the transmitter is tuned up with the THRULINE in place, the load impedance will be very different when it is removed.

The THRULINE, of course, indicates zero reflection when the load, at its load connector, is 50 ohms, pure resistive. An ideal condition on a 70-ohm line on the load side of the THRULINE will show 3% reflected power, i.e., THRULINE load is 70 ohms resistive, VSWR in the 50-ohm THRULINE is 70/50 = 1.4. The THRULINE can also show this same reflected percentage with 50/1.4 = 35.7 ohms pure resistive load which could exist with 10% reflected power on the 70-ohm line (VSWR = 2 on the 70-ohm line). From this you can see that the 70-ohm line could have as much as 10% reflected power and VSWR = 2 when the THRULINE indicates 3% reflected power of VSWR = 1.4.

It should be especially remembered that with 70-ohm lines it is most important to get the reflected power indication and subtract it from the forward, because of this factor being so much more critical here than with intended 50-ohm line.

TABLE I — STANDARD ELEMENTS (CAT. NOS.)

TYPE	Freq. Band MHz	WATTS FULL SCALE									
		5	10	25	50	100	250	500	1000	2500	5000
H	2-30	-	-	-	50H	100H	250H	500H	1000H	2500H	5000H
A	25-60	5A	10A	25A	50A	100A	250A	500A	1000A	-	-
B	50-125	5B	10B	25B	50B	100B	250B	500B	1000B	-	-
C	100-250	5C	10C	25C	50C	100C	250C	500C	1000C	-	-
D	200-500	5D	10D	25D	50D	100D	250D	500D	1000D	-	-
E	400-1000	5E	10E	25E	50E	100E	250E	500E	1000E	-	-

In addition to the Standard Types listed above, other special Elements are provided as follows: (See Bird Gen. Catalog)

Table II — Low Power Elements 1 and 2.5 watts in nine narrow band units from 60 to 950 MHz.

Table III — High Frequency Elements 1, 2.5, 5, 10, and 25 watts in four frequency bands; 950-1260 MHz, 1100-1800 MHz, 1700-2200 MHz and 2200-2300 MHz, respectively.

Table IV — Low Frequency Elements 1K, 2.5K, 5K, and 10K watts in one frequency band; .45 to 2.5 MHz.

SPECIAL NOTE

For the convenience of users, a set of VSWR conversion nomographs is appended to this handbook. With these charts, VSWR's may be directly ascertained from forward and reverse power values read from the THRULINE Wattmeter.

SECTION 5
MAINTENANCE

1. INTRODUCTION

With the simple construction and generally self-contained nature of the THRULINE equipment, there is only a moderate amount of maintenance required. One of the major precautions is in handling; use reasonable care and do not drop the THRULINE equipment or the Plug-In Elements.

The main factor in maintenance is care and cleanliness. The Element socket should be kept plugged as much as possible to prevent the intrusion of dust. When a Plug-In Element is used for this purpose (use highest power Element available), it should be positioned with the ARROW pointing upwards. This protects the meter and will not expose the Element crystal to dangerous potentials if the RF line section should be energized. If any of the contacts or line connectors become dirty, they should be cleaned with a little dry cleaning solvent, Inhibisol* or its equivalent, or trichlorethylene, on a cotton swab stick. Avoid excessive skin contact or inhalation of fumes when using. Observe special care if carbon tetrachloride is used. Clean all contact areas and especially the exposed faces of the Teflon* insulators.

It is particularly important to keep the mating surfaces of the socket and Plug-In Element clean. This applies to the bore of the socket and the circumference of the THRULINE Element body, but most important to the bottom rim of the Element body and the seat at the base of the socket in the line section. Also, check the ends of the insulated dc contacts on the THRULINE Element to see that they are clean and smooth. These parts should be carefully cleaned with a cotton swab stick and dry cleaning solvent, as above. There must be a good contact between the base of the Plug-In Element and its socket to assure stable operation of the THRULINE.

In cleaning the socket bore, the operator should be careful not to disturb the spring finger of the dc contact. It is important that the operating position of this part be properly maintained. If the spring finger of the dc contact requires adjustment, it may be done manually if carried out with care. The button must be positioned far enough out to maintain good contact with the Element, but not so as to interfere with easy entry of the Element body. The dc jack (with spring finger) may be removed for access by unscrewing the two #4-40 fillister head machine screws which fasten it to the side of the RF line section. Then retract its assembly, watching carefully not to lose the small teflon positioning bead that straddles the base of the phosphor bronze spring and nests in a counterbore on the side of the RF body. When replacing the assembly, be sure that the bead is again properly inserted.

If there is any evidence of the contamination inside the RF line section, the reachable portions should be likewise wiped and the interior carefully blown out. Under no circumstances attempt to remove the RF center conductor. It is tightly frozen in place and any attempt to remove it will ruin the assembly. Keep all connections tight, and keep the nut of the meter cord plug turned tight on the line section dc jack. This connection may often be serviced by simply loosening the nut of the dc plug, swinging the body several times through a fraction of a turn, and retightening the knurled nut securely.

There are no replacement parts furnished with this equipment. As previously mentioned, components of these matched units cannot be interchanged or individually replaced. The replaceable portions to the Line Section are standard parts of the coaxial line fastenings.

2. TROUBLE SHOOTING

As a brief guide to the operator in isolating occasional difficulties that may occur in the use of the THRULINE, the following summary is included. The remedies for same are referenced to the text in this section or are self-evident:

DIFFICULTY	POSSIBLE CAUSES
No Meter Indication	No radio frequency power. Arrow on Plug-In Element pointing wrong direction. No pick-up from dc contact finger in the RF line section — adjust per Paragraph 1. Open or short circuit in dc meter cable — replace defective cable (RG-58/U) Meter burned out or damaged.
Intermittent or inconsistent meter readings.	Faulty load. Faulty transmission line. Dirty dc contacts on Elements — Clean as in Paragraph 1. Sticky or defective meter.
High VSWR or high percent reflected power.	Bad load, or poor connectors — see Paragraph 1. Shorted or open transmission line. Foreign material in line section or in RF connector bodies — See Paragraph 1.

3. CALIBRATION CHECKS—THRULINE VS. TERMALINE WATTMETERS

It is recognized that calibration of absorption wattmeters is difficult and likely to be inaccurate unless comparison is made with a transmission (through) type of standard. The THRULINE being of such type, a natural question is: can a THRULINE be used to check or recalibrate absorption wattmeters, such as the Bird Electronic TERMALINE, both being rated at ±5 percent accuracy? The main question is one of exact power calibration.

The answer is a qualified yes, although with both instruments being about equally old and known to be undamaged, there is not too much reason to prefer either on probable accuracy. The edge is somewhat in favor of the THRULINE, because each Element covers only 2-1/2 to 1 in frequency and will be flatter originally over this range than the TERMALINE can be held initially over its very much wider (16.7 to 1) frequency range. Also the THRULINE will probably exhibit smaller changes with time, because of the narrower frequency range, because it is simpler in general design and easier in function (does not have to serve as a power load), and because it does not become heated in operation.

Certainly if the absorption wattmeter has gone years since calibration, or is reasonably suspected of inaccuracy, it may well be calibrated against the THRULINE as standard. (Rather than use correction factors, one can, with the TERMALINE Wattmeter, make use of the calibration adjustment screws used in factory calibration. These are concealed and not mentioned in instruction book to discourage tampering. Correspondence is necessary.)

If such calibration is undertaken, care and thoroughness are advised.

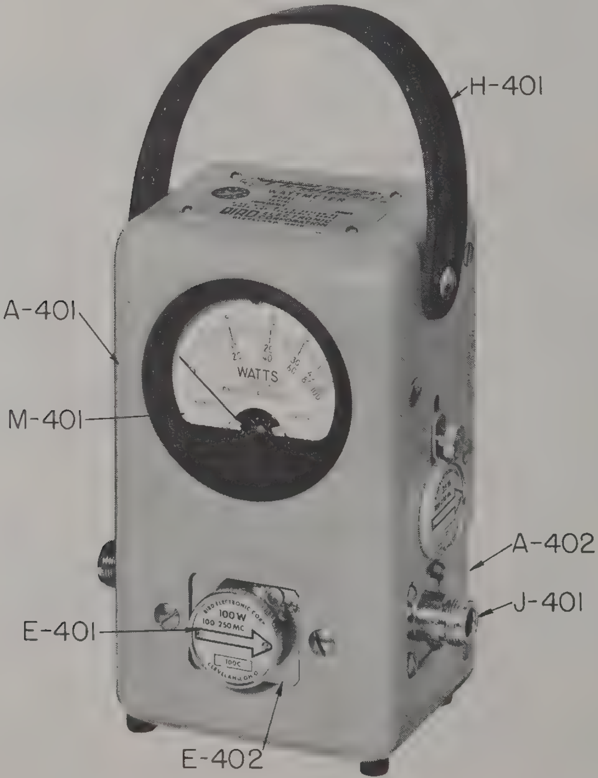
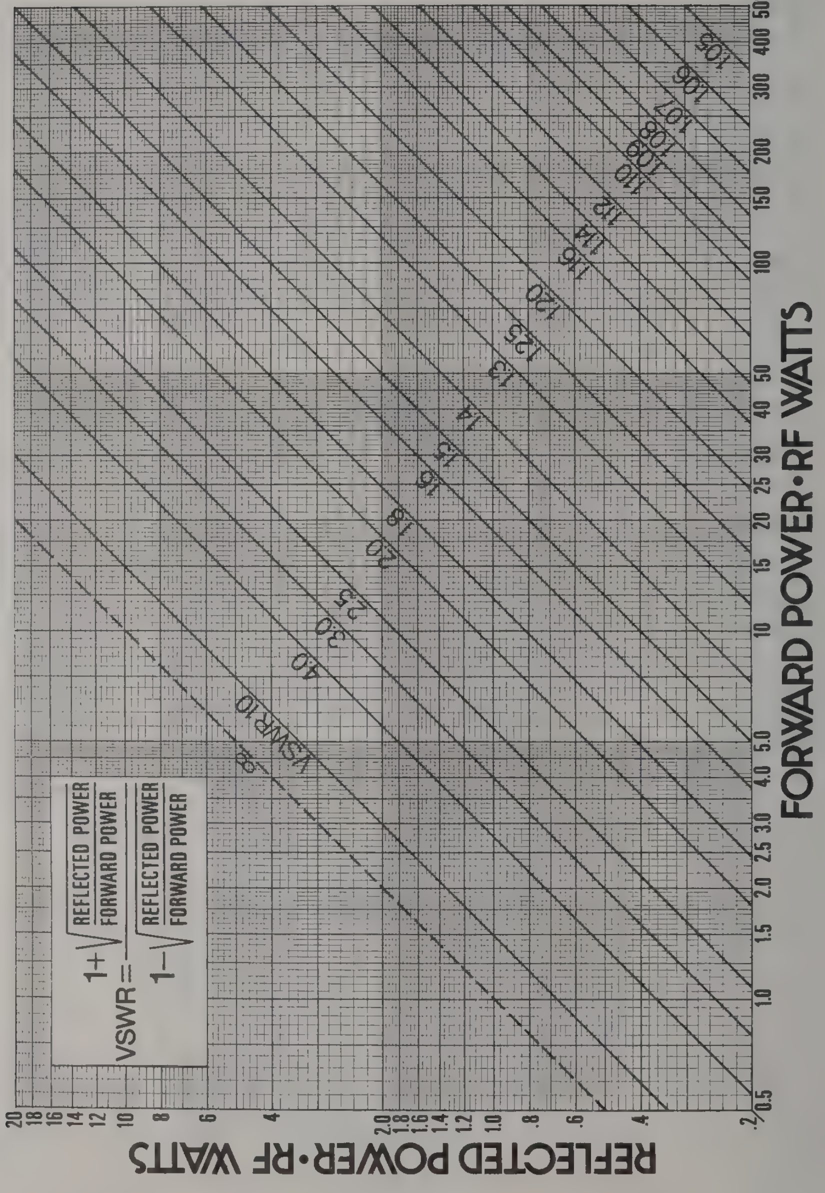


Fig. 5-1. Parts Illustration.

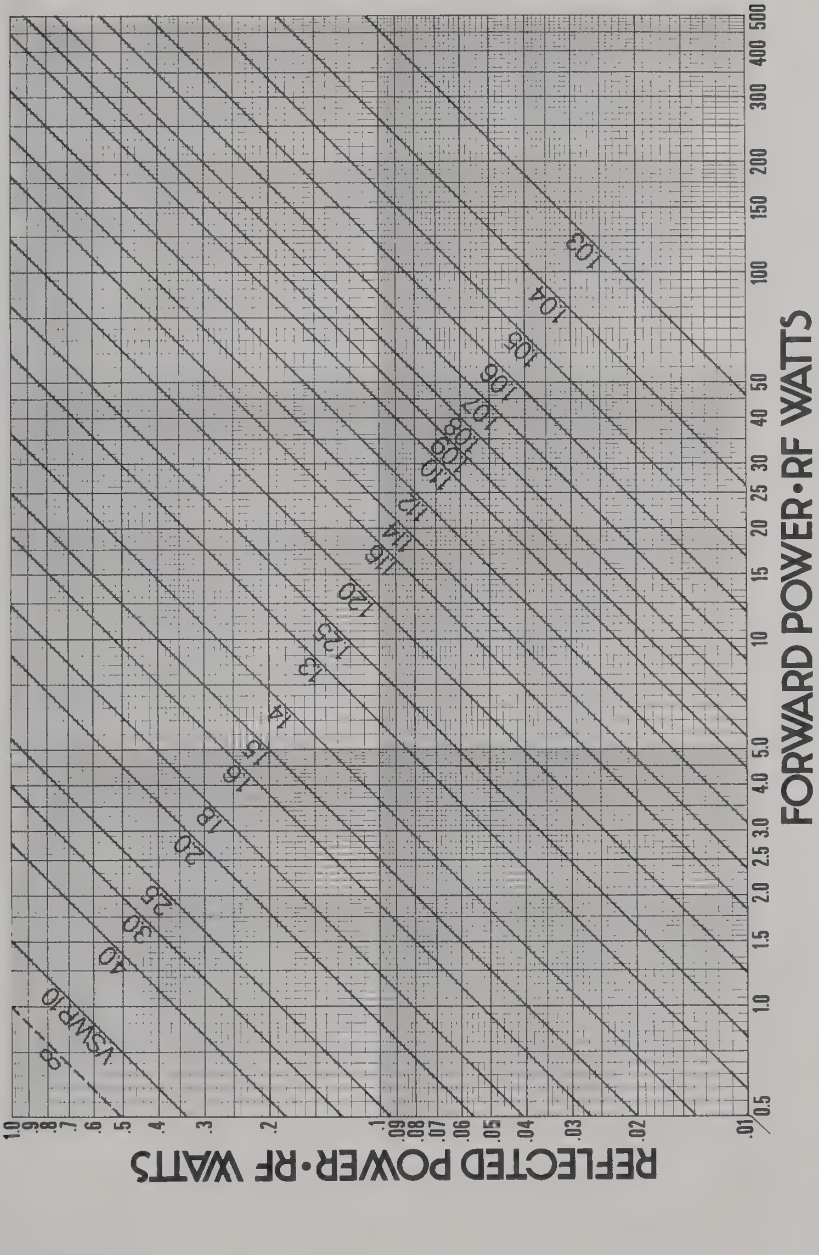
SECTION 6 - PARTS LIST

Reference Designation	Part Name and Description	Function	Drawing No.
A-401	Housing Assembly: Aluminum die casting, 7 lg x 4w x 3h, w/latch and thumbscrew each side for spare Elements, four rubber bumpers on base, leather carrying strap at top. Gray Enamel.	Houses and protects meter, holds RF line section and spare Element.	4210-018
A-402	Cover Assembly: Aluminum alloy sheet, .040 thk., 6-1/2 lg x 4w x 1-1/2h overall, has four rubber bumpers and slot closing ears. Gray Enamel.	Closes back of housing.	4210-005
E-401	Elements, Plug-In: Brass, w/teflon bottom cover, 1-7/16 lg x 1-1/4 cap dia. x 1 body dia. Gold Plate. Furnished in power and frequency types per Table I, Section 4.	Measuring Element for THRULINE.	4250-020
E-402	Line Section Assembly: Brass Casting, normally supplied w/two female "N" connectors, 5-1/8 lg x 1-1/4w x 1-15/16h, 50-ohm line section and socket for Plug-In Element. Has dc jack at side. Nickel Plate.	RF Line insertion section and measuring base.	4230-018
H-401	Carry Strap: Black Leather, 9 lg between centers, 5/32 x 7/8 section.	Carries meter housing.	8580-003
J-400	Connectors, RF: All types have 1-1/4 sq. mtg. flange, and 1/8 dia. x 5/16 lg. slotted connector pin at rear. Brass, with Teflon insulator. Nickel plate. Fifteen types, viz:	RF connection for standard type connectors.	See individual part numbers listed below.
J-401	Female "N" - 1-5/32 lg.		4240-062
J-402	Male "N" - 1-1/4 lg.		4240-063
J-403	Female "HN" - 1-5/32 lg.		4240-268
J-404	Male "HN" - 1-3/8 lg.		4240-278
J-405	Female "C" - 1-1/16 lg.		4240-100
J-406	Male "C" - 1-7/16 lg.		4240-110
J-407	Female UHF (SO-239) 1-1/4 lg.		4240-050
J-408	Male UHF (PL-259) 1-5/8 lg.		4240-179
J-409	Female "BNC" - 1-5/32 lg.		4240-125
J-410	Male "BNC" - 1-9/32 lg.		4240-132
J-413	Female "LC" - 2-1/32 lg.		4240-031
J-414	Male "LC" - 2-1/2 lg.		4240-025
J-415	Female "LT" - 2-3/32 lg.		4240-018
J-416	Male "LT" - 2-1/2 lg.		4240-012
J-417	7/8" EIA Air Line 2-3/4 lg.		4240-002
J-411	DC Connector Assembly: Brass fitting, w/phosphor bronze spring at rear, 1" dia. flange x 1-1/4 overall, 5/8 -24 thd. on connector body, center contact on front, teflon insulators. Nickel Plate.	DC Jack for line section assembly.	4230-010
M-401	Microammeter: 30ua full scale. Flush 3-1/2" bakelite case, solder terminals, special scale.	Meter for power reading. (For replacement usually furnished as 8-000 Kit.	2080-002
	Replacement Meter Kit Consisting of: 1 - 2080-002 Meter 1 - 4220-097-1 Cable Assembly 3 - 4220-098 Bumper Feet		8-000
P-401	Connector, Plug: Part of cable W-403, Brass fitting 1-1/4 lg x 5/8h x 3/4d, water proof. Nickel Plate. Navy type DS-491859.	DC Plug for RG-58/U meter cord.	7500-076
W-403	Meter Cable Assembly: RG-58/U cable, 2-3/4 feet long, w/dc plug P-401 at one end.	Meter Cord.	4220-097-1

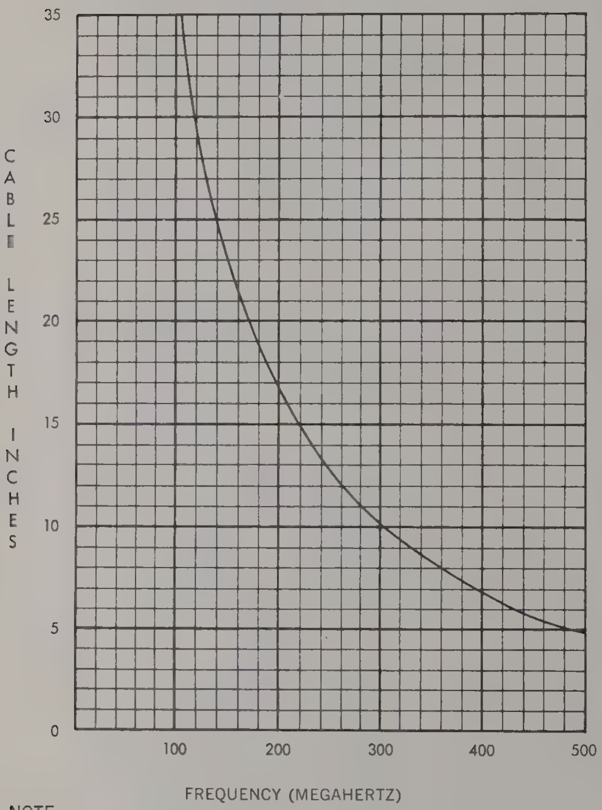
appendix


VSWR = (1 + √(REFLECTED POWER / FORWARD POWER)) / (1 − √(REFLECTED POWER / FORWARD POWER))
REFLECTED POWER • RF WATTS
20
18
16
14
12
10
8
6
4
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
FORWARD POWER • RF WATTS
0.5
1.0
1.5
2.0
2.5
3.0
4.0
5.0
10
15
20
25
30
40
50
100
150
200
300
400
500
∞
VSWR 10
4.0
3.0
2.5
2.0
1.8
1.6
1.5
1.4
1.3
1.25
1.20
1.16
1.14
1.12
1.10
1.09
1.08
1.07
1.06
1.05

Following the vertical and horizontal grid, determine intersection of forward and reverse power values. Slanted lines passing closest to this point indicate VSWR.



Required Length of RG-8/U Cable With Connectors When added to Bird Model 43 Thruline to Equal 1/2 Wavelength



NOTE:

1. When using UHF Plug 259 the cable length is measured from tip to tip of center pin of plugs.
2. When using other connectors the cable length is measured from end to end of outer conductor of connectors.

When a "43" is used to match a load to a transmitter and a good match is obtained, removing the instrument will not cause any change in the conditions, since a good 50-ohm load can be placed at the end of a 50-ohm transmission line of any length without altering conditions at the transmitter.

What happens when the load is not well matched, like an antenna with a VSWR of 1.5 or 2.0? Since the length of line between a mismatched load and the source transforms the impedance of the load as seen at the source, line length now becomes critical. If the adjustments for maximum power transfer were made with the "43" in place, removing it shortens the line by 4 inches, plus two connectors. This still is no cause for concern at low frequencies, where 4 to 5 inches is a small fraction of a wavelength. At higher frequencies (e.g. above 100 MHz), power output and frequency of the source may be affected.

It is a principle of transmission line theory that the impedance is identical on either side of ½ wavelength. In order to duplicate the conditions in your transmission line with the "43" either in or out of the line, it is only necessary to insert or remove a one-half wavelength.

This is easily done by making up a length of cable which, when added to the THRULINE, equals ½ wavelength at the frequency of measurement. (If more than one frequency is involved, one cable is needed for each frequency.)

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From 2 to 2300 MHz and from 25 milliwatts
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ATTENUATORS

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INSTRUCTION BOOK

for the

Thruline

WATTMETER

MODEL 43

BIRD ELECTRONIC CORP.
CLEVELAND, OHIO

BIRD- MAN H. J. Zylstra

J.H. JAMES
30303 AURORA ROAD
CLEVELAND 39, OHIO
CHURCHILL 8-1200

INSTRUCTION BOOK

for the

Thruline

WATTMETER

MODEL 43

BIRD ELECTRONIC CORP.
CLEVELAND, OHIO

SUMMARY SHEET

Circuit - 50-ohm impedance - THRULINE

Measures - R-F Power - 10W to 500W Full Scale Direct Reading in Watts, Frequency Range 25 - 1000 MC in five element types, See Table I, Section 4.

Insertion VSWR - Less than 1.05 VSWR up to 1000 MC

Accuracy - ±5% of Full Scale Power

Dimensions - Basic Overall 7"lg x 4"w x 3"h

Weight - 4 Pounds

Connectors - Female and Male "N"

Female and Male "HN"

Female and Male "C"

Female UHF (SO 239)

Not supplied on regular orders

2 Female "N" Connectors standard with equipment, unless otherwise specified.

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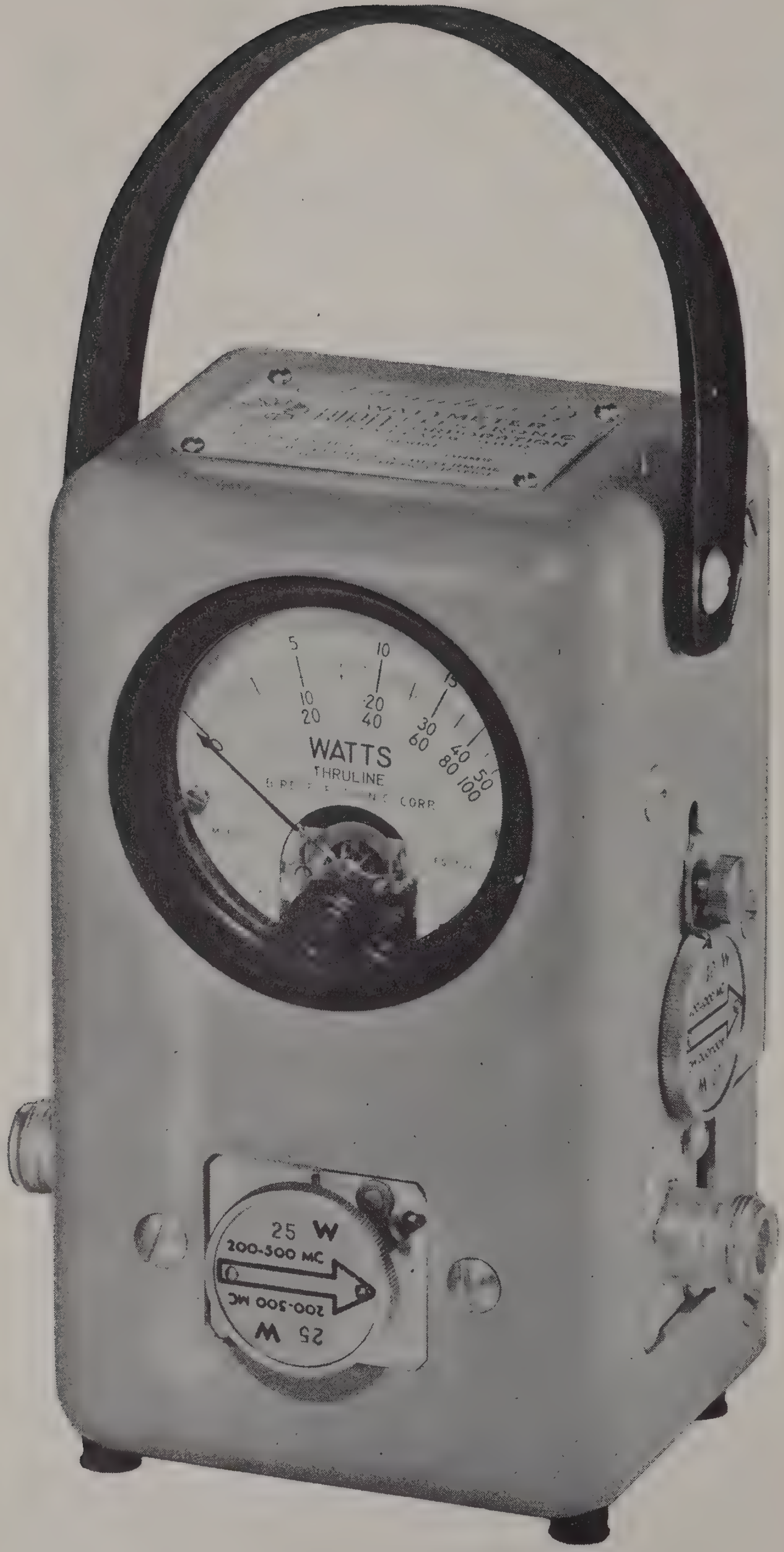


Fig. 1-1. View of Model 43 THRULINE

SECTION 1
GENERAL DESCRIPTION

1. PURPOSE AND APPLICATION

The Model 43 THRULINE WATTMETER is a directional r-f wattmeter, which measures power flow and load match in coaxial lines. It is for use with CW, AM, FM, and TV modulation envelopes, but is not for use on pulsed transmitters. Model 43 is designed for 50-ohm application, the insertion VSWR being less than 1.05 for frequencies up to 1000 MC in a standard 50-ohm circuit. The meter is direct reading (30ua d-c full scale), expanded down-scale for easy reading, and is graduated 25, 50, and 100 watts full scale. Further characteristics of the unit may be found in the summary sheet on page A.

2. DESCRIPTION (See Fig. 1-1)

The THRULINE WATTMETER is a portable unit contained in a die cast aluminum housing, with removable formed metal enclosure at the rear. The unit includes a leather carrying strap, four rubber bumper feet on the base, and four rubber bumpers on the back for use in standing or flat-laying applications. For further mechanical protection the microammeter is shock mounted between a hollow rubber back-up ring and three stem bumpers on the front flange of the meter. On the lower front face of the meter there is a slotted adjustment screw to zero the pointer. Below the meter opening is a rectangular aperture, at the front, through which projects only the top face of the line section casting, with the measuring element socket in the center.

A cable, entirely shielded against stray or r-f interference, connects the microammeter to the d-c jack attached to the side of the line section casting. This cable is nearly three feet in length, and permits the r-f line section to be removed from the housing. Connections to the meter may be readily maintained for any installations outside of the housing. Through the use of extra r-f bodies, permanent auxiliary installations may be maintained. See Section 3, INSTALLATIONS.

The d-c jack assembly has a filter capacitor nested inside, which shunts across the meter cable circuit. This more fully protects meter readings against the adverse effect of any stray r-f energy existant in the plug-in element. The d-c jack mounts a phosphor bronze spring finger. This opens into the plug-in element socket through a lateral clearance hole in the line section. The finger has a small silver button near its end, which mates with the contacts on the inserted elements. The line section is a silver plated brass casting, precision produced to provide unimpaired impedance of the r-f coaxial line in which it is inserted. For additional mechanical support the ends of the line section are machined to accurate size and nested in mating slots in the side wall of the housing. The r-f connectors at each end are of a quick-change type, being fastened down only by the four screws of the respective mounting flanges. The housing does not interfere with any connector changes.

To make measurements, the cylindrically shaped plug-in elements are inserted in the socket of the line section. A small catch in the upper right hand corner of the casting face presses on the shoulder of the plug-in element body, thereby maintaining the element in steady alignment with an assured bottom contact, to provide the most consistent electrical operation. The plug-in element has its terminals on diametrically opposite sides of the body, so that pick-up is made in either direction. The contacts on the plug-in element make connection with the d-c pick-up button only when the plug-in element is in the precise forward or reverse position. The small index pin on the element must be on the lower level of the casting face and against its respective stop.

The meter scale, as described above, is read according to the full scale rating stamped on the cap of the plug-in measuring element. These elements also fall in five frequency band groups, more fully described in Section 4, Paragraph 1.

SECTION 2
THEORY OF OPERATION

1. TRAVELLING WAVE VIEWPOINT

It is simplest to visualize the THRULINE idea from the TRAVELLING WAVE viewpoint on transmission lines, which shows that the voltages, currents, standing waves, etc., on any uniform section of line are the resultants of two travelling waves:

FORWARD WAVE travels (and its power flows) from source to load, has r-f voltage E and current I in phase, with $E/I = Z_0$

REFLECTED WAVE originates by reflection at the load, travels (and its power flows) from load to source and also has its voltage $\mathcal{E}$ and current $\mathcal{I}$ in phase, with $\mathcal{E}/\mathcal{I} = Z_0$

Note that each component wave is mathematically simple, and is completely described by a single figure for power, for instance:

$$\overset{F}{W} = \text{Watts Forward} = E^2/Z_0 = I^2 Z_0 = EI$$

$$\overset{R}{W} = \text{Watts Reflected} = \mathcal{E}^2/Z_0 = \mathcal{I}^2 Z_0 = \mathcal{E}\mathcal{I}$$

Z_0 is the characteristic impedance of the uniform line, and simplifies things by being a pure resistance, usually 50 ohms, for useful lines. The r-f main line circuit of the THRULINE is a short uniform section of air line, whose Z_0 is exactly 50 ohms, and in which accurate measurements may be made.

2. COUPLING CIRCUIT

The coupling circuit which is sampling the travelling waves is in the plug-in element. The circuitry of the element and its relationship to the other components of the THRULINE are shown in the schematic diagram, Fig. 2-1. Energy will be produced in the coupling circuit of the element both by mutual inductance and capacitance from the travelling r-f waves of the line section. The inductive currents will of course flow according to the direction of the travelling waves producing them. The capacitative portion of these currents is naturally independent of the direction of the travelling waves. Therefore, assuming that the element remains stationary, it is apparent that the current produced from the waves of one direction will add in phase, while those of the opposite direction will subtract in phase. The additive or "ARROW" direction is of course assigned to the forward wave, while the element is so designed and carefully balanced that the currents produced from the reverse wave will cancel each other almost completely. The resultant is a directivity always higher than 35db, which means that the element is highly insensitive (nulled) to the "REVERSE" direction wave. Being highly directional, the THRULINE ELEMENT is sensitive, at one setting, only to one of the travelling waves which produce standing waves by interference. THRULINE measurements are therefore independent of position along standing waves. It may be said that the THRULINE doesn't know, doesn't care and doesn't need to care where it is along a standing wave.

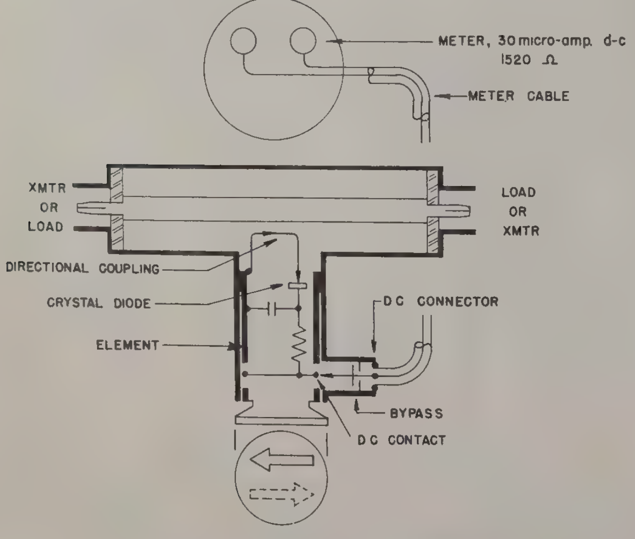


Fig. 2-1. Schematic Diagram

3. STANDING WAVE RATIO vs. REFLECTED/FORWARD POWER RATIO

As mentioned above, the THRULINE uses a TRAVELLING WAVE viewpoint to measure most of the significant facts about transmission line operation. The STANDING WAVE viewpoint is another, quite elaborately developed, both mathematically and in existing instruments, which is widely used. Relationships between these viewpoints and their mathematical systems are given in most high frequency texts.

It is believed here that the more widespread use of the standing wave viewpoint and mathematics can be traced to the earlier development of slotted lines as exploring tools with which quantitative figures are obtained from the line. The slotted line is a standing wave instrument in fact, and use of it emphasizes the standing wave viewpoint.

There is not much question that slotted lines are too long, too expensive if good, not portable, and are slow and exacting in operation, these objections increasing rapidly as frequency drops below 1000 MC. The THRULINE is surprisingly quick, convenient and accurate by comparison. With the exception of reflection phase angle (distance, load to minimum) it tells everything a slotted line will tell.

SECTION 3
INSTALLATION

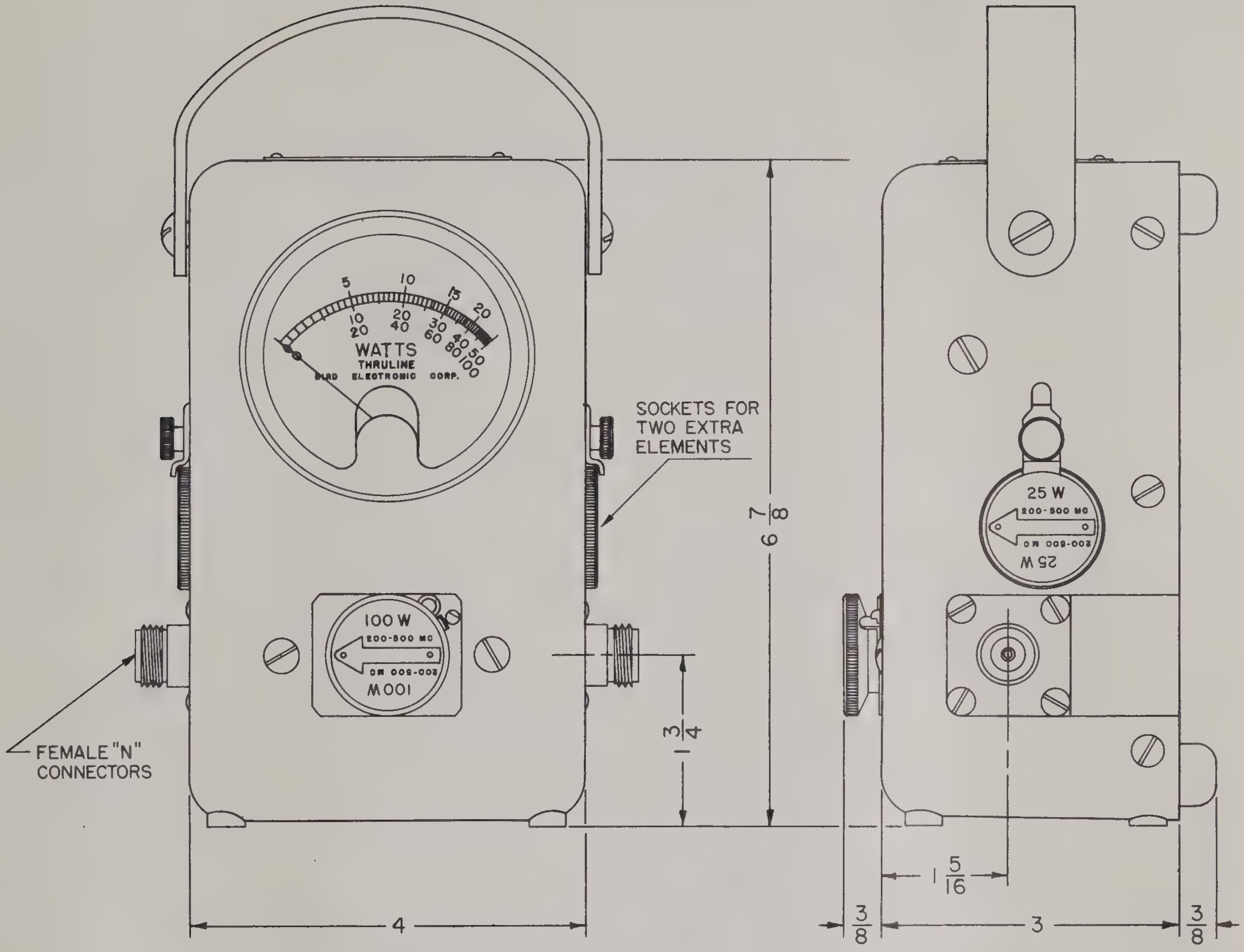


Fig. 3-1. Outline Drawing, Model 43 THRULINE

1. PORTABILITY

The Model 43 is essentially a portable instrument, and the housing is not specifically designed for attached mounting, see Outline Drawing, Fig. 3-1. A strap is provided for carrying purposes. Special Precaution - while transporting the THRULINE, it is best to insert a Plug-In Element and point the ARROW UPWARDS. This will shunt the meter connection circuit and serve to actively dampen needle action during handling or shipping. Also, at these times, secure the spare Plug-In Elements firmly by use of the thumbscrews for each socket. A fall could disrupt the calibration of the Elements, and they should be handled with reasonable care at all times.

DO NOT DROP the THRULINE or subject it to hard blows. The microammeter is shock mounted in the housing to protect it against ordinary hazards, but its delicate mechanism may be damaged by severe impact.

The r-f line section, Fig. 3-2, may be removed from the housing for use elsewhere than in the meter housing. This may be accomplished by unscrewing the six #8-32 flat head machine screws around the back (three on each side). Then grasp the back cover by the side filler tabs and pull directly backwards. The entire back assembly will come off, with the speed nuts remaining attached. Now the line section may be loosened by removing the two #10-32 oval head machine screws on the front of the housing, right in line with the r-f section axis. It may now be slid directly backwards right out of the housing.

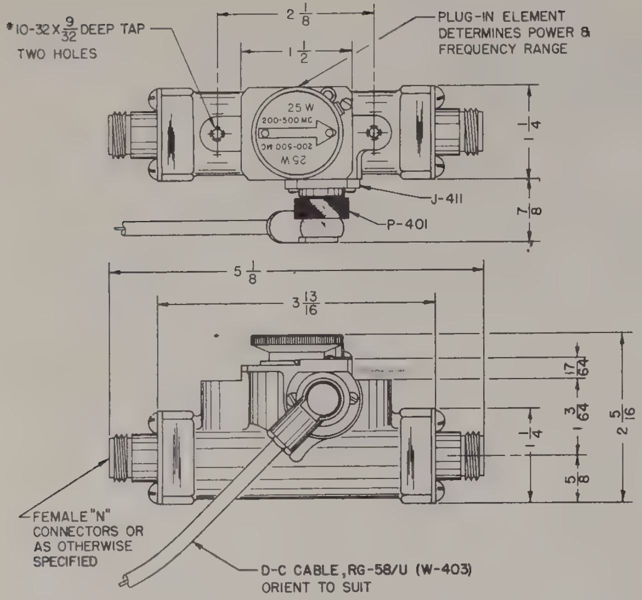

#10-32 X 9/32 DEEP TAP
TWO HOLES
2 1/8
1 1/2
PLUG-IN ELEMENT DETERMINES POWER & FREQUENCY RANGE
25 W
200-500 MC
1 1/4
J-411
P-401
7/8
5 1/8
3 13/16
17/64
1 3/64
2 5/16
1 1/4
5/8
FEMALE "N" CONNECTORS OR AS OTHERWISE SPECIFIED
D-C CABLE, RG-58/U (W-403) ORIENT TO SUIT

Fig. 3-2. Installation Drawing, R-F Line Section

2. REMOTE INSTALLATION

It is frequently advisable to mount the r-f section in a fixed location, particularly above 200 MC, to keep r-f lines short and to allow rigid connections without flexible cables. The standard meter cable, coiled within the housing, is 2-3/4 feet long. Longer meter cables are available on special order, 25 feet being a semi-stock length. As long as shielded cable is used (preferably RG-58/U), users may improvise their own extension cables. Additional interchangeable r-f bodies (Fig. 3-2) are available. It may be desirable to have two or more such bodies permanently installed in continuously operating equipment. In this case, one set of elements and one meter may be used to measure several r-f lines WITHOUT INTERRUPTION OF R-F LINES for insertion of the THRULINE.

If it is desired to panel mount the r-f line section, it blends very readily to this type of installation. A layout for the panel mount cutting is given in Fig. 3-3. The preferred panel thickness is 1/4 inch, but variations thicker or thinner will be acceptable. The use of a properly designed shim plate or of washers will make installation with thinner panels quite satisfactory. To simplify cable connections the r-f line section may be mounted in any convenient direction. Attach the r-f unit so that the finger catch is in the most accessible position.

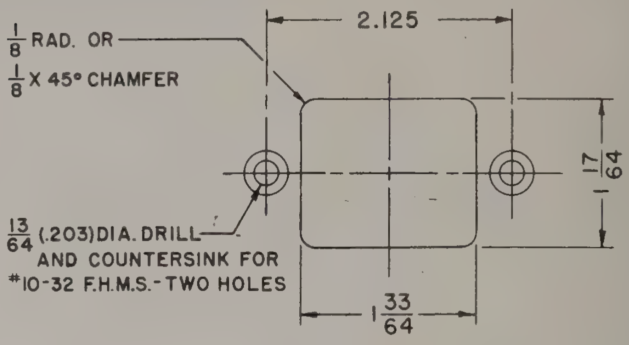

1/8 RAD. OR
1/8 X 45° CHAMFER
2.125
17/64
13/64 (.203) DIA. DRILL AND COUNTERSINK FOR #10-32 F.H.M.S.- TWO HOLES
1 33/64

Fig. 3-3. Panel Cut for Mounting R-F Body

3. CONNECTIONS

The THRULINE is inserted in an r-f circuit with any suitable coaxial cable of 50-ohms impedance only. It is quite indifferent as to which respective side the power source and the load connections are made. If cables of other than 50-ohms impedance are used, mismatch will occur and introduce probably serious inaccuracies in the readings. We strongly urge the avoidance of this condition. Nevertheless, in the possible event of need, the calculation of results from same are discussed in Section 4, Para. 7.

The equipment is normally supplied with two female "N" type connectors. Connection is readily made with male "N" cable plugs. However, the following types of these quick-change connectors are now available:

Female "N"
Male "N"
Female "HN"
Male "HN"
Female "C"
Male "C"
Female UHF (SO-239)
Male UHF (PL-259)
Female "BNC"
Male "BNC"
Female "LC"
Male "LC"
Female "LT"
Male "LT"
7/8" EIA Air Line

These may be purchased from Bird Electronic Corp. as required. See Parts List, Section 6. Any of these above connectors can be changed readily by removing the #8-32 round head machine screws at each corner of the square flanges, and pulling straight outwards, carefully disengaging the spring fingers of the center conductor. Reverse this procedure to attach the connectors.

SECTION 4
OPERATION

1. GENERAL

The apparent features of the THRULINE equipment have been discussed in Section 1, GENERAL DESCRIPTION, and in the instructions of Section 3, INSTALLATION. Measurements are made by the insertion and operation of the plug-in elements previously mentioned.

The elements determine the power range to be read on the meter scale, and the major markings (viz. 50W, 100W, etc.) are the FULL SCALE POWER value for that element. Elements are also marked for FREQUENCY RANGE. The transmitter frequency must be within the band of the element used. Elements are available according to those identified in the table below.

See paragraph 4 of this chapter for frequency band flatness, and performance of the elements outside of stated frequencies. Elements for additional ranges (power or frequency) may be ordered without returning the THRULINE for calibration, since the r-f bodies and meters are standardized, and are designed for a wide range of coaxial transmission power values and frequencies.

ARROW on plug-in element indicates Sensitive DIRECTION, i.e., the direction of power flow which the meter will read. ARROW and REVERSE are directional terms used in reference to the THRULINE ELEMENT, and mean respectively the sensitive and null directions of the element. ROTATE ELEMENT to reverse the sensitive direction. FORWARD and REFLECTED are directional terms used in reference to the source - load circuit. Note that the transmitter may attach to either connector of the THRULINE. It makes no difference which external r-f connection is selected, since the elements are reversible and the r-f circuit is symmetrical end for end. Before taking readings be sure that the meter pointer has been properly zeroed under no-power conditions.

The THRULINE used with a TERMALINE resistor of proper power rating forms a highly useful absorption wattmeter. With ARROW set toward the load, it is unnecessary to reverse because reflected power may be neglected.

In cases where readings are being made when the meter unit is connected to an auxiliary r-f line section body, always remove any measuring element from the unused r-f line section. Otherwise, the d-c circuit will be unbalanced or shorted according to the arrow position of the other element, causing inaccurate or no reading on the meter.

2. LOAD POWER

Power delivered to (and dissipated in) a load is given by:

$$\overset{L}{W} = \text{Watts into Load} = \overset{F}{W} - \overset{R}{W}$$

i.e., where appreciable power is reflected, as with an antenna, it is necessary to subtract reflected from forward power to get load power. This correction is negligible (less than 1 percent) if the load is such as to have a VSWR of 1.2 or less. Good load resistors, such as our TERMALINES, will thus show negligible or unreadable reflected power.

VSWR scales, and their attendant controls, for setting the reference point, have been intentionally omitted from the THRULINE for two reasons:

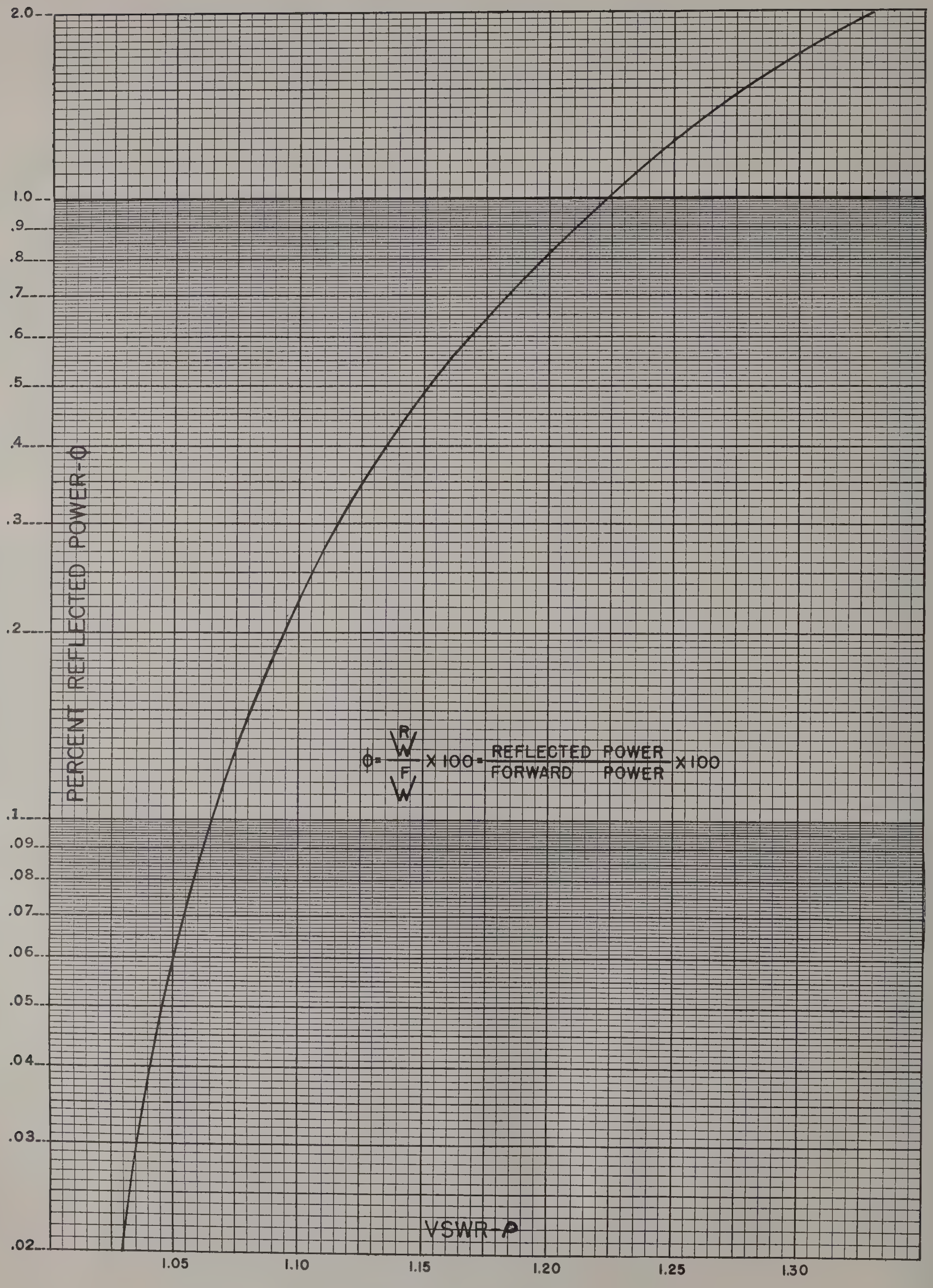
(a) Why make something similar to a hypothetical d-c volt ohmmeter with control pots for the voltmeter multipliers? Even more complications arise when diodes at r-f are involved.

(b) Experience using the THRULINE on transmitter tune-up, antenna matching etc., i.e., on OPERATING PROBLEMS shows that the power ratio ϕ is no mean competitor, in practical usefulness, to the ratio ρ = VSWR.

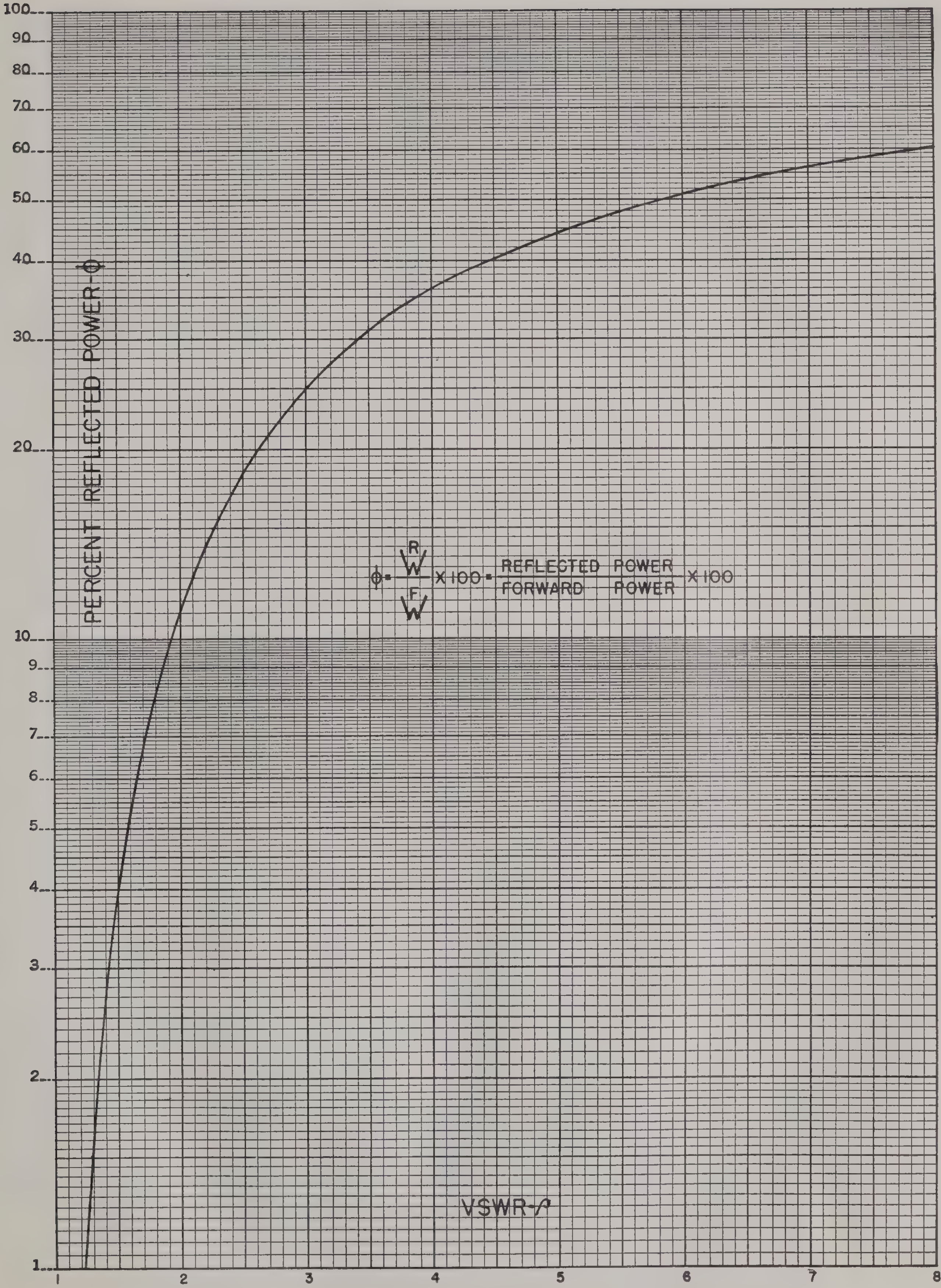
TABLE 1—RANGE OF ELEMENT TYPES

STANDARD THRULINE ELEMENT TYPES									
TYPE	Frequency Band - Mcs	WATTS FULL SCALE							
		5	10	25	50	100	250	500	1000
H	2-30	-	-	-	50H	100H	250H	500H	1000H
A	25-60	5A	10A	25A	50A	100A	250A	500A	1000A
B	50-125	5B	10B	25B	50B	100B	250B	500B	1000B
C	100-250	5C	10C	25C	50C	100C	250C	500C	1000C
D	200-500	5D	10D	25D	50D	100D	250D	500D	1000D
E	400-1000	5E	10E	25E	50E	100E	250E	500E	1000E

1 and 2.5 watt element made on special order for narrow frequency ranges, except 2-30 mc ("H" Band)



4-1a. Graph. - Percent Reflected Power vs. VSWR (1.0 to 1.3).



4-1b. Graph. - Percent Reflected Power vs. VSWR (1.0 to 8.0).

A trial is suggested for a few days -- forget VSWR and try thinking in terms of $\phi = \overset{R}{W} / \overset{F}{W}$ when the THRULINE is used. It will be noted that, even without bothering to calculate the ratio exactly, the two meter readings $\overset{R}{W}$ and $\overset{F}{W}$ give an automatic mental impression which pictures the situation. Thus, in an antenna matching problem, the main thing usually is to minimize $\overset{R}{W}$, and anything done experimentally to this end is directly indicated when the THRULINE is in the reflected position. Furthermore, the ratio of readings, only mentally evaluated, is a reliable guide to the significance of the remaining reflected power.

3. GRAPH—ρ VS. ϕ AND ITS SIGNIFICANCE

Since there are definite simple relationships

$$\rho = \frac{1+\sqrt{\phi}}{1-\sqrt{\phi}} \text{ and } \phi = \left[\frac{\rho-1}{\rho+1}\right]^2 \text{ where } \rho = \text{VSWR and } \phi = \frac{\overset{R}{W}}{\overset{F}{W}}$$

between standing wave ratio ρ and the reflected/forward power ratio ϕ indicated by the THRULINE, the latter may be conveniently used to measure VSWR. The relationship is given in Fig. 4-1a and b.

Note, that around $\phi = 10\%$, below which $\overset{R}{W}$ will appear insignificant and become hard to read, you are close to the commonly accepted lower limit $\rho = 2$, below which improved antenna match becomes less and less worthwhile in many systems. Experimentally, using the THRULINE, it is readily shown that minimizing ϕ below 10% produces little gain in $\overset{L}{W}$. TV transmitter antenna lines, and VHF OMNIRANGE transmitters, are among systems requiring much lower levels of reflected power for reasons other than simple power transmission. Note also in Fig. 4-1a, the very small level of reflected power, $\phi = .06$ percent, corresponding to $\rho = 1.05$. With a single element, detection of reflected power is possible down to about $\phi = 1$ percent, $\rho = 1.2$; if $\overset{F}{W}$ approaches full scale, measurement is possible down to about $\phi = 5$ percent, $\rho = 1.5$.

LOW-REFLECTION MEASUREMENTS may be extended below this with two elements. Say 80 watts are available, and you have 100 watt and 10 watt elements.

> Measure $\overset{F}{W}$ with the 100 watt element. Remove 100 W element and insert 10 watt element.
>
> CAUTION: 10 watt element must be ONLY in the REFLECTED direction. ARROW toward

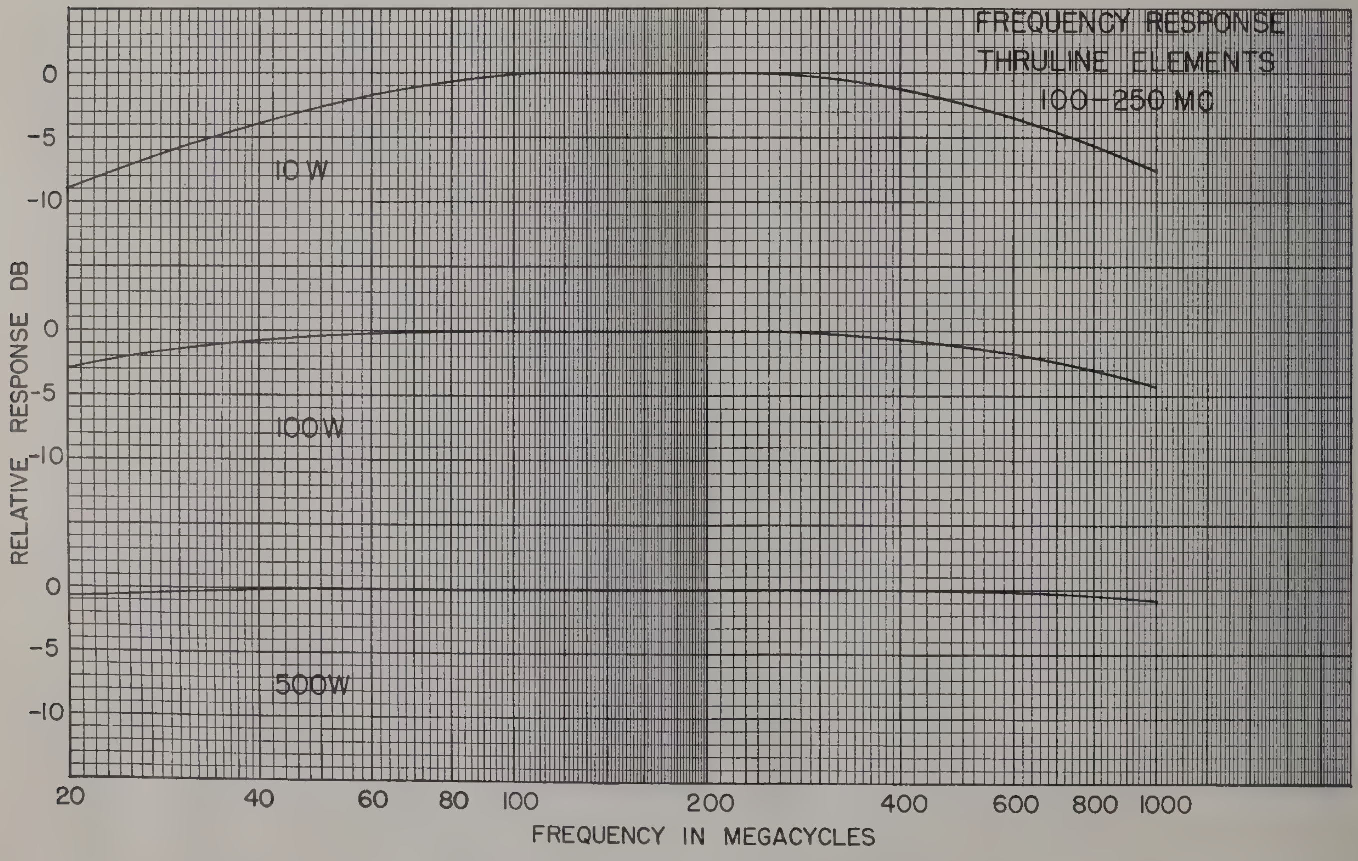


Fig. 4-2. Graph - Frequency Response

TRANSMITTER. Insert and remove ONLY this way.

Now read $\overset{R}{W}$ on the 10 watt element.

SPECIAL NOTE

DON'T ROTATE 10 watt element while TRANSMITTER is on. Always use great care with LOW SCALE elements on HIGH power r-f lines. Inadvertent exposure of these elements to too much FORWARD or even too high reflected power may permanently damage the measuring element or the microammeter.

In this case, measurement down to at least .5 watt reflected is possible which means to

$\phi = \frac{.5}{80},$ say .6 percent, or to about $\rho = 1.16$

and detection of reflections is possible down to about .1 watt,

$\phi = \frac{.1}{80} = .00125,$ say .1 percent, or to about $\rho = 1.06$

Caution is necessary in the above method, and preferably it should not be used with element ranges differing more than 100 to 10, although 250 to 10 can be used with extreme caution. With available elements no more sensitive than 10 watts full scale, as at present, the above method is limited to use with higher powered transmitters.

4. FREQUENCY RESPONSE

The plug-in elements have a very flat frequency response over a frequency ratio of more than 2-1/2 to one. This characteristic provides a practically flat response within the assigned frequency ranges for all the elements, see Table I in this Section.

An illustrative set of curves for three elements of one of these frequency bands is shown in Fig. 4-2. Notice that on the LOW POWER element, the fall-off above and below the assigned frequency band is more pronounced than it is for the HIGH POWER element. The degree of drop in response varies progressively less for each power level from low to high, with the average difference at approximately the mean power level. These curves, Fig. 4-2, may be assumed to be about typical for all of the listed band types (A, B, C, D & E) at their respective stated frequencies.

Harmonics, or sub-harmonics, may be known to exist in the measured circuit (outside of the element frequency band). If so, a rough approximation of the response of the element to these harmonics may be made by the use of these curves. The frequency ordinate to be read on the graph will be obtained by proportioning the frequency of the element used with that of the one illustrated. Interpolation of the curve values will give an approximation of the extent that these harmonic signals are being measured by your element.

The use of the elements for direct power measurements outside of their stated frequency range is not recommended.

5. MEASUREMENT & MONITORING OF TRANSMITTER POWER

Little more need be said about this, in view of LOAD POWER paragraph above. The THRULINE is useful for continuous monitoring of transmitter output, and may be found useful in continuous monitoring of reflected power, for instance in checking intermittent antenna or line faults.

Like diode devices generally, the THRULINE indicates the carrier component on amplitude modulation, with very little response to sideband components added by modulation.

6. TESTING OF LINES, CONNECTORS, FILTERS, ETC.

The THRULINE is highly useful for this purpose, and may be employed in several ways.

(a) VSWR (Insertion) or ϕ (Insertion) may be measured with the line terminated in a good load resistor (Termaline). The lower limits of sensitivity in this are given above under LOW REFLECTION MEASUREMENTS.

(b) ATTENUATION (Power lost by heat in the line) as well as VSWR (Insertion) and ϕ (Insertion) may be measured by inserting the unknown line between two THRULINES, or between two r-f bodies used with one meter and one set of elements. (End of line to be terminated in a load resistor). This method applies also to insertion between the THRULINE and a TERMALINE absorption wattmeter.

Very small values of attenuation require allowance for normal instrument errors. The correction may be determined by direct rigid connection of the THRULINES, or of the THRULINE-TERMALINE combination, in cascade. Slight juggling of zero settings is permissible for convenience in eliminating computation, provided readings are being taken fairly well up on scale.

(c) ATTENUATION BY OPEN OR SHORT CIRCUIT METHOD. Neater by far than (b) method is one depending on the high directivity (null balance) to which the THRULINE elements are held. They should, and do, exhibit good equality between forward and reflected readings when the load connector is open or short circuited. In this condition $\phi = 100$ percent, the forward and reflected waves being equal in magnitude, and $\rho = \infty$ Say that this is checked on open circuit, and then a length of line of unknown attenuation, also open circuited, is connected to the load connector. The ratio ϕ then shown is the attenuation in two passes along the line (down and back).

Expressed in db, (using the equation $N_{db} = 10 \log \frac{W_F}{W_R}$), the db figure may be compared with published data for line type and length by remembering to halve N_{db}* because twice the line length is actually being measured.

This measurement should be supplemented by one of Ø (Insertion) as in (a) above, or at least by d-c continuity and leakage checks, since the attenuation measurement alone can be in error from faults such as open or short circuits part way down the line.

Open circuit testing is somewhat to be preferred to short circuit, since the reference short (used to check equality initially) must be good, and because the initial equality is somewhat better on open than on short circuit.

Again, for quite low values of measured attenuation, it is advisable to note exact readings (or difference) on the initial equality check, and to allow for this difference.

7. IMPEDANCE MISMATCH

There may be cases where it is necessary to use the THRULINE on other than the 50-ohm circuit for which it is designed.

Using the THRULINE, you will be inserting a 4-inch length of 50-ohm air line and the load on the transmitter will be changed from its original condition without the THRULINE. For a power reflection factor under 10% and frequency below 200 MC, the 4-inch length mismatch is not too serious. But going any higher than these values, even if the transmitter is tuned up with the THRULINE in place, the load impedance will be very different when it is removed.

The THRULINE, of course, indicates zero reflection when the load, at its load connector, is 50 ohms, pure resistive. An ideal condition on a 70-ohm line on the load side of the THRULINE will show 3% reflected power, i.e., THRULINE load is 70 ohms resistive, VSWR in the 50-ohm THRULINE is 70/50 = 1.4. The THRULINE can also show this same reflected percentage with 50/1.4 = 35.7 ohms pure resistive load, which could exist with 10% reflected power on the 70-ohm line (VSWR = 2 on the 70-ohm line). From this you can see that the 70-ohm line could have as much as 10% reflected power and VSWR = 2 when the THRULINE indicates 3% reflected power or VSWR = 1.4.

It should be especially remembered that with 70-ohm lines it is most important to get the reflected power indication and subtract it from the forward, because of this factor being so much more critical here than with intended 50-ohm line.

---

*Or to double the line length.

SECTION 5
MAINTENANCE

1. INTRODUCTION

With the simple construction and generally self-contained nature of the THRULINE equipment, there is only a moderate amount of maintenance required. As stated in Section 1, one of the major precautions is in handling; use reasonable care and do not drop the THRULINE equipment or the plug-in elements.

The main factor in maintenance is care and cleanliness. The element socket should be kept plugged as much as possible against the intrusion of dust. When a plug-in element is used for this purpose (use highest power element available), it should be positioned with the ARROW pointing upwards. This protects the meter and will not expose the element crystal to dangerous potentials if the r-f line section should be energized. The r-f connectors should be also protected against dirt and grime, either by keeping cable plugs in place, or by other suitable means. Quick-change connectors that are not mounted should be stored in a closed place. In handling and storing these, care should be used to avoid damaging the special contact prongs protruding from the inside face. If the r-f connectors become dirty, they should be cleaned with a cotton swab stick and carbon tetrachloride. Do not use any other fluid. Avoid breathing fumes when using. Clean all contact areas and especially the exposed faces of the teflon insulators.

It is particularly important to keep the mating surfaces of the socket and the plug-in element clean. This applies to the bore of the socket and the circumference of the cylinder body, but most importantly to the bottom rim of the body and the seat at the base of the socket in the line section. Also, check the ends of the insulated d-c contacts on the body to see that they are clean and smooth. These parts should be carefully cleaned with cotton swab stick and carbon tetrachloride as above. There must be good contact between the base of the plug-in element and its socket to assure stable operation of the THRULINE.

In cleaning the socket bore, the operator should be careful not to disturb the spring finger of the d-c contact. It is important that the operating position of this part be properly maintained. If the spring finger of the d-c contact requires adjustment, this may be done manually if carried out with care. The button must be positioned far enough out to maintain good contact with the element, but not so as to interfere with easy entry of the element body. The d-c jack (with spring finger) may be removed for access by unscrewing the two #4-40 fillister head machine screws that fasten it to the side of the r-f line section. Then retract this assembly, watching carefully not to lose the small teflon positioning bead that straddles the base of the phosphor bronze spring and nests in a counterbore on the side of the r-f body. When replacing the assembly, be sure that the bead is again properly inserted.

If there is any evidence of contamination inside the r-f line section, the reachable portions should be likewise wiped and the interior carefully blown out. Under no circumstances attempt to remove the r-f line conductor. It is tightly frozen in place, and any effort to move it will ruin the assembly. Keep all connections tight, and keep the nut of the meter cord plug turned tight on the line section d-c jack. This connection may often be serviced by simply loosening the nut of the d-c plug, swinging the body several times through a fraction of a turn, and retightening the knurled nut securely.

Except for zero-ing the meter, it requires no maintenance. The mechanism of the microammeter is very delicate. Do not tamper with it. See Parts List with Figs. 5-1 and 3-2 for illustration of the parts discussed in this section.

2. TROUBLE SHOOTING

As a brief guide to the operator in isolating occasional difficulties that may occur in the use of the THRULINE, we add the following summary. The remedies for same are referenced to the text or are self-evident:

DIFFICULTY	POSSIBLE CAUSES
No Meter Indication	Arrow on Plug-In Element pointing wrong direction. No radio frequency power. No pick-up from d-c contact finger in r-f line section - adjust per paragraph 1. Open or short circuit in d-c meter cable - replace defective cable (RG-58/U) Meter burned out or damaged.
Intermittent or inconsistent meter readings.	Faulty load. Faulty transmission line. Dirty d-c contacts on elements - Clean as in paragraph 1. Sticky or defective meter.
High VSWR or high % power reflected.	Bad load. Poor connectors - See paragraph 1. Shorted or open transmission line. Foreign material in line section or in r-f connector bodies - see paragraph 1.

3. CALIBRATION CHECKS—THRULINE VS. TERMALINE WATTMETERS

It is recognized that calibration of absorption wattmeters is difficult and likely to be inaccurate unless comparison is made with a transmission (through) type of standard. The THRULINE being of such type, a natural question is: can a THRULINE be used to check or recalibrate absorption wattmeters, such as the Bird Electronic TERMALINE, both being rated at ±5 percent accuracy? The main question is one of exact power calibration.

The answer is a qualified yes, although with both instruments being about equally old and known to be undamaged, there is not too much reason to prefer either on probable accuracy. The edge is somewhat in favor of the THRULINE, because each element covers only 2-1/2 to 1 in frequency and will be flatter originally over this range than the TERMALINE can be held initially over its very much wider (16.7 to 1) frequency range. Also the THRULINE will probably exhibit smaller changes with time, because of the narrower frequency range, because it is simpler in general design and easier in function (does not have to serve as a power load), and because it does not become heated in operation.

Certainly if the absorption wattmeter has gone years since calibration, or is reasonably suspected of inaccuracy, it may well be calibrated against the THRULINE as standard. (Rather than use correction factors, one can, with the TERMALINE Wattmeter, make use of the calibration adjustment screws used in factory calibration. These are concealed and not mentioned in instruction book to discourage tampering. Correspondence is necessary.)

If such calibration is undertaken, care and thoroughness are advised.

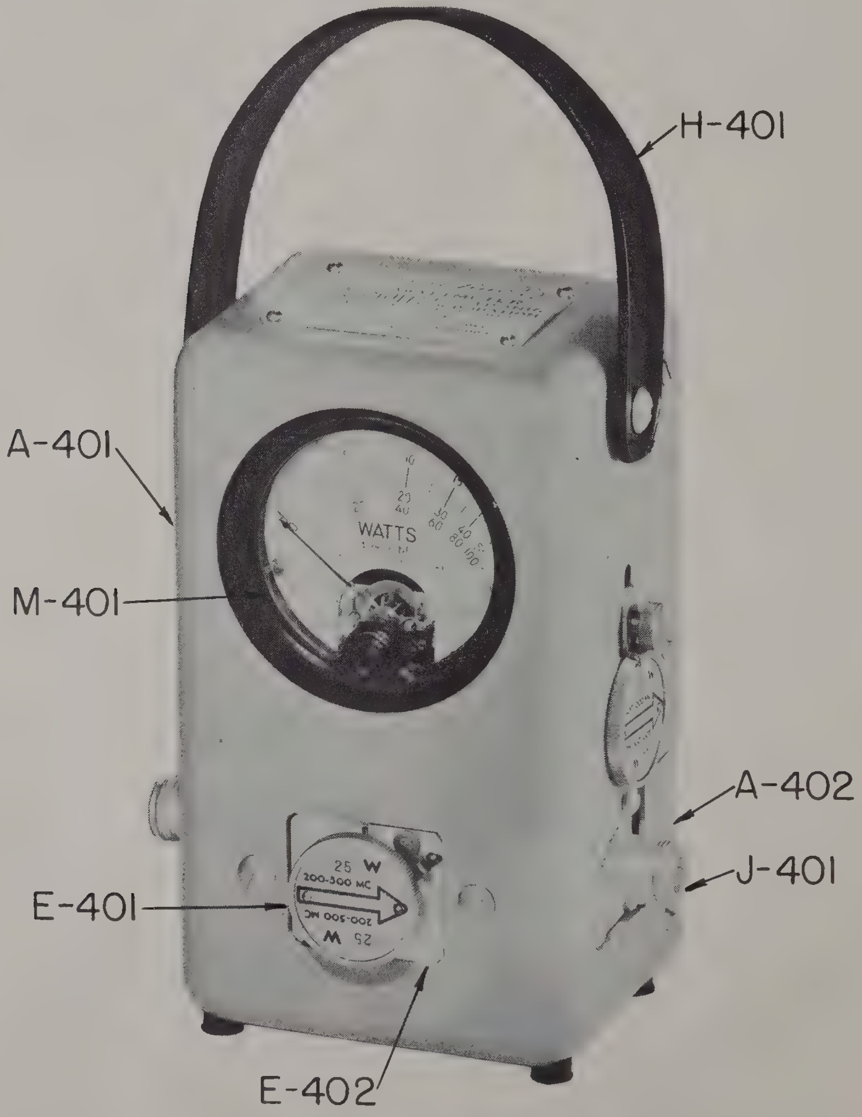


Fig. 5-1. Parts Illustration.

SECTION 6 - PARTS LIST

Reference Designation	Part Name and Description	Function	Drawing No.
A-401	Housing Assembly: Aluminum die casting, 7 lg x 4w x 3h, w/latch and thumbscrew each side for space elements, four rubber bumpers on base, leather carrying strap at top. Gray Enamel.	Houses and protects meter, holds r-f line section and spare element.	421018
A-402	Cover Assembly: Aluminum alloy sheet, .040 thk., 6-1/2 lg x 4w x 1-1/2h overall, has four rubber bumpers and slot closing ears. Gray Enamel.	Closes back of housing.	421005
E-401	Elements, Plug-In: Brass, w/teflon bottom cover, 1-7/16 lg x 1-1/4 cap dia. x 1 body dia. Gold Plate. Furnished in power and frequency types per Table I, Section 4, Paragraph 1.	Measuring element for THRULINE.	425020
E-402	Line Section Assembly: Brass Casting, normally supplied w/two female "N" connectors, 5-1/8 lg x 1-1/4w x 1-15/16h, 50-ohm line section and socket for plug-in element. Has d-c jack at side. Silver Plate.	R-F Line insertion section and measuring base.	423018
H-401	Carry Strap: Black Leather, 9 lg between centers, 5/32 x 7/8 section.	Carries meter housing.	85803
J-400	Connectors, RF: All types have 1-1/4 sq. mtg. flange, and 1/8 dia. x 5/16 lg. slotted connector pin at rear. Brass, with Teflon insulator. Silver plate. Fifteen types, viz:	RF connection for standard type connectors.	See individual part numbers listed below.
J-401	Female "N" - 1-5/32 lg.		424062
J-402	Male "N" - 1-1/4 lg.		424063
J-403	Female "HN" - 1-5/32 lg.		424073
J-404	Male "HN" - 1-3/8 lg.		424049
J-405	Female "C" - 1-1/16 lg.		424100
J-406	Male "C" - 1-7/16 lg.		424110
J-407	Female UHF (SO-239) 1-1/4 lg.		424050
J-408	Male UHF (PL-259) 1-5/8 lg.		424173
J-409	Female "BNC" - 1-5/32 lg.		424125
J-410	Male "BNC" - 1-9/32 lg.		424132
J-413	Female "LC" - 2-1/32 lg.		424031
J-414	Male "LC" - 2-1/2 lg.		424025
J-415	Female "LT" - 2-3/32 lg.		424018
J-416	Male "LT" - 2-1/2 lg.		424012
J-417	7/8" EIA Air Line 2-3/4 lg.		424002
J-411	D-C Connector Assembly: Brass fitting, w/phosphor bronze spring at rear, 1 dia. flange x 1-1/4 overall, 5/8 -24 thd. on connector body, center contact on front, teflon insulators. Silver Plate.	D-C Jack for line section assembly.	423010
M-401	Microameter: Weston Model 306, 1400-ohm resistance, 30ua full scale. Flush 3-1/2" bakelite case, solder terminals, special scale.	Meter for power reading. (For replacement usually furnished as #8000 Kit.	208002
	Replacement Meter Kit Consisting of: 1 - 208002 Meter 1 - 422097-1 Cable Assembly 3 - 422098 Bumper Feet		8000
P-401	Connector, Plug: Part of cable W-403, Brass fitting 1-1/4 lg x 5/8h x 3/4d, water proof. Silver Plate. Navy type DS-491859.	D-C Plug for RG-58/U meter cord.	75076
W-403	Meter Cable Assembly: RG-58/U cable, 2-3/4 feet long, w/d-c plug P-401 at one end.	Meter Cord.	422097-1

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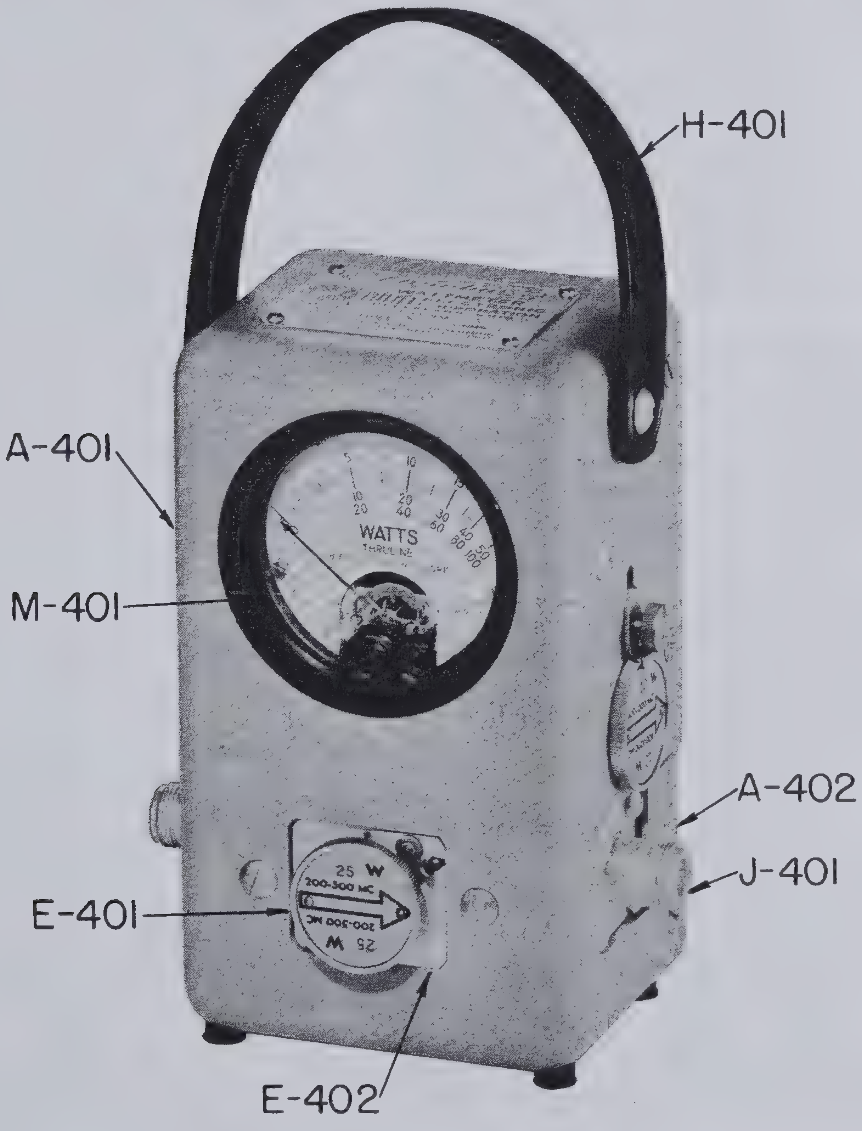

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The main factor in maintenance is care and cleanliness. The element socket should be kept plugged as much as possible against the intrusion of dust. When a plug-in element is used for this purpose (use highest power element available), it should be positioned with the ARROW pointing upwards. This protects the meter and will not expose the element crystal to dangerous potentials if the r-f line section should be energized. The r-f connectors should be also protected against dirt and grime, either by keeping cable plugs in place, or by other suitable means. Quick-change connectors that are not mounted should be stored in a closed place. In handling and storing these, care should be used to avoid damaging the special contact prongs protruding from the inside face. If the r-f connectors become dirty, they should be cleaned with a cotton swab stick and carbon tetrachloride. Do not use any other fluid. Avoid breathing fumes when using. Clean all contact areas and especially the exposed faces of the teflon insulators.

It is particularly important to keep the mating surfaces of the socket and the plug-in element clean. This applies to the bore of the socket and the circumference of the cylinder body, but most importantly to the bottom rim of the body and the seat at the base of the socket in the line section. Also, check the ends of the insulated d-c contacts on the body to see that they are clean and smooth. These parts should be carefully cleaned with cotton swab stick and carbon tetrachloride as above. There must be good contact between the base of the plug-in element and its socket to assure stable operation of the THRULINE.

In cleaning the socket bore, the operator should be careful not to disturb the spring finger of the d-c contact. It is important that the operating position of this part be properly maintained. If the spring finger of the d-c contact requires adjustment, this may be done manually if carried out with care. The button must be positioned far enough out to maintain good contact with the element, but not so as to interfere with easy entry of the element body. The d-c jack (with spring finger) may be removed for access by unscrewing the two #4-40 fillister head machine screws that fasten it to the side of the r-f line section. Then retract this assembly, watching carefully not to lose the small teflon positioning bead that straddles the base of the phosphor bronze spring and nests in a counterbore on the side of the r-f body. When replacing the assembly, be sure that the bead is again properly inserted.

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High VSWR or high % power reflected.	Bad load. Poor connectors - See paragraph 1. Shorted or open transmission line. Foreign material in line section or in r-f connector bodies - see paragraph 1.

Expressed in db, (using the equation $N_{db} = 10 \log \frac{\overset{F}{W}}{\overset{R}{W}}$), the db figure may be compared with published data for line type and length by remembering to halve N_{db}* because twice the line length is actually being measured.

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The THRULINE, of course, indicates zero reflection when the load, at its load connector, is 50 ohms, pure resistive. An ideal condition on a 70-ohm line on the load side of the THRULINE will show 3% reflected power, i.e., THRULINE load is 70 ohms resistive, VSWR in the 50-ohm THRULINE is 70/50 = 1.4. The THRULINE can also show this same reflected percentage with 50/1.4 = 35.7 ohms pure resistive load, which could exist with 10% reflected power on the 70-ohm line (VSWR = 2 on the 70-ohm line). From this you can see that the 70-ohm line could have as much as 10% reflected power and VSWR = 2 when the THRULINE indicates 3% reflected power or VSWR = 1.4.

It should be especially remembered that with 70-ohm lines it is most important to get the reflected power indication and subtract it from the forward, because of this factor being so much more critical here than with intended 50-ohm line.

---

*Or to double the line length.

TRANSMITTER. Insert and remove ONLY this way.

Now read $\overset{R}{W}$ on the 10 watt element.

SPECIAL NOTE

DON'T ROTATE 10 watt element while TRANSMITTER is on. Always use great care with LOW SCALE elements on HIGH power r-f lines. Inadvertent exposure of these elements to too much FORWARD or even too high reflected power may permanently damage the measuring element or the microammeter.

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$$\phi = \frac{.1}{80} = .00125\text{, say .1 percent, or to about } \rho = 1.06$$

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The plug-in elements have a very flat frequency response over a frequency ratio of more than 2-1/2 to one. This characteristic provides a practically flat response within the assigned frequency ranges for all the elements, see Table I in this Section.

An illustrative set of curves for three elements of one of these frequency bands is shown in Fig. 4-2. Notice that on the LOW POWER element, the fall-off above and below the assigned frequency band is more pronounced than it is for the HIGH POWER element. The degree of drop in response varies progressively less for each power level from low to high, with the average difference at approximately the mean power level. These curves, Fig. 4-2, may be assumed to be about typical for all of the listed band types (A, B, C, D & E) at their respective stated frequencies.

Harmonics, or sub-harmonics, may be known to exist in the measured circuit (outside of the element frequency band). If so, a rough approximation of the response of the element to these harmonics may be made by the use of these curves. The frequency ordinate to be read on the graph will be obtained by proportioning the frequency of the element used with that of the one illustrated. Interpolation of the curve values will give an approximation of the extent that these harmonic signals are being measured by your element.

The use of the elements for direct power measurements outside of their stated frequency range is not recommended.

5. MEASUREMENT & MONITORING OF TRANSMITTER POWER

Little more need be said about this, in view of LOAD POWER paragraph above. The THRULINE is useful for continuous monitoring of transmitter output, and may be found useful in continuous monitoring of reflected power, for instance in checking intermittent antenna or line faults.

Like diode devices generally, the THRULINE indicates the carrier component on amplitude modulation, with very little response to sideband components added by modulation.

6. TESTING OF LINES, CONNECTORS, FILTERS, ETC.

The THRULINE is highly useful for this purpose, and may be employed in several ways.

(a) VSWR (Insertion) or ϕ (Insertion) may be measured with the line terminated in a good load resistor (Termaline). The lower limits of sensitivity in this are given above under LOW REFLECTION MEASUREMENTS.

(b) ATTENUATION (Power lost by heat in the line) as well as VSWR (Insertion) and ϕ (Insertion) may be measured by inserting the unknown line between two THRULINES, or between two r-f bodies used with one meter and one set of elements. (End of line to be terminated in a load resistor). This method applies also to insertion between the THRULINE and a TERMALINE absorption wattmeter.

Very small values of attenuation require allowance for normal instrument errors. The correction may be determined by direct rigid connection of the THRULINES, or of the THRULINE-TERMALINE combination, in cascade. Slight juggling of zero settings is permissible for convenience in eliminating computation, provided readings are being taken fairly well up on scale.

(c) ATTENUATION BY OPEN OR SHORT CIRCUIT METHOD. Neater by far than (b) method is one depending on the high directivity (null balance) to which the THRULINE elements are held. They should, and do, exhibit good equality between forward and reflected readings when the load connector is open or short circuited. In this condition ϕ = 100 percent, the forward and reflected waves being equal in magnitude, and $\rho = \infty$ Say that this is checked on open circuit, and then a length of line of unknown attenuation, also open circuited, is connected to the load connector. The ratio ϕ then shown is the attenuation in two passes along the line (down and back).

A trial is suggested for a few days -- forget VSWR and try thinking in terms of $\phi = \overset{R}{W} / \overset{F}{W}$ when the THRULINE is used. It will be noted that, even without bothering to calculate the ratio exactly, the two meter readings $\overset{R}{W}$ and $\overset{F}{W}$ give an automatic mental impression which pictures the situation. Thus, in an antenna matching problem, the main thing usually is to minimize $\overset{R}{W}$, and anything done experimentally to this end is directly indicated when the THRULINE is in the reflected position. Furthermore, the ratio of readings, only mentally evaluated, is a reliable guide to the significance of the remaining reflected power.

3. GRAPH—ρ VS. ϕ AND ITS SIGNIFICANCE

Since there are definite simple relationships

$$\rho = \frac{1+\sqrt{\phi}}{1-\sqrt{\phi}} \text{ and } \phi = \left[\frac{\rho-1}{\rho+1}\right]^2 \text{ where } \rho = \text{VSWR and } \phi = \frac{\overset{R}{W}}{\overset{F}{W}}$$

between standing wave ratio ρ and the reflected/forward power ratio ϕ indicated by the THRULINE, the latter may be conveniently used to measure VSWR. The relationship is given in Fig. 4-1a and b.

Note, that around ϕ = 10%, below which $\overset{R}{W}$ will appear insignificant and become hard to read, you are close to the commonly accepted lower limit ρ = 2, below which improved antenna match becomes less and less worthwhile in many systems. Experimentally, using the THRULINE, it is readily shown that minimizing ϕ below 10% produces little gain in $\overset{L}{W}$. TV transmitter antenna lines, and VHF OMNIRANGE transmitters, are among systems requiring much lower levels of reflected power for reasons other than simple power transmission. Note also in Fig. 4-1a, the very small level of reflected power, ϕ = .06 percent, corresponding to ρ = 1.05. With a single element, detection of reflected power is possible down to about ϕ = 1 percent, ρ = 1.2; if $\overset{F}{W}$ approaches full scale, measurement is possible down to about ϕ = 5 percent, ρ = 1.5.

LOW-REFLECTION MEASUREMENTS may be extended below this with two elements. Say 80 watts are available, and you have 100 watt and 10 watt elements.

> Measure $\overset{F}{W}$ with the 100 watt element. Remove 100 W element and insert 10 watt element.
>
> CAUTION: 10 watt element must be ONLY in the REFLECTED direction. ARROW toward

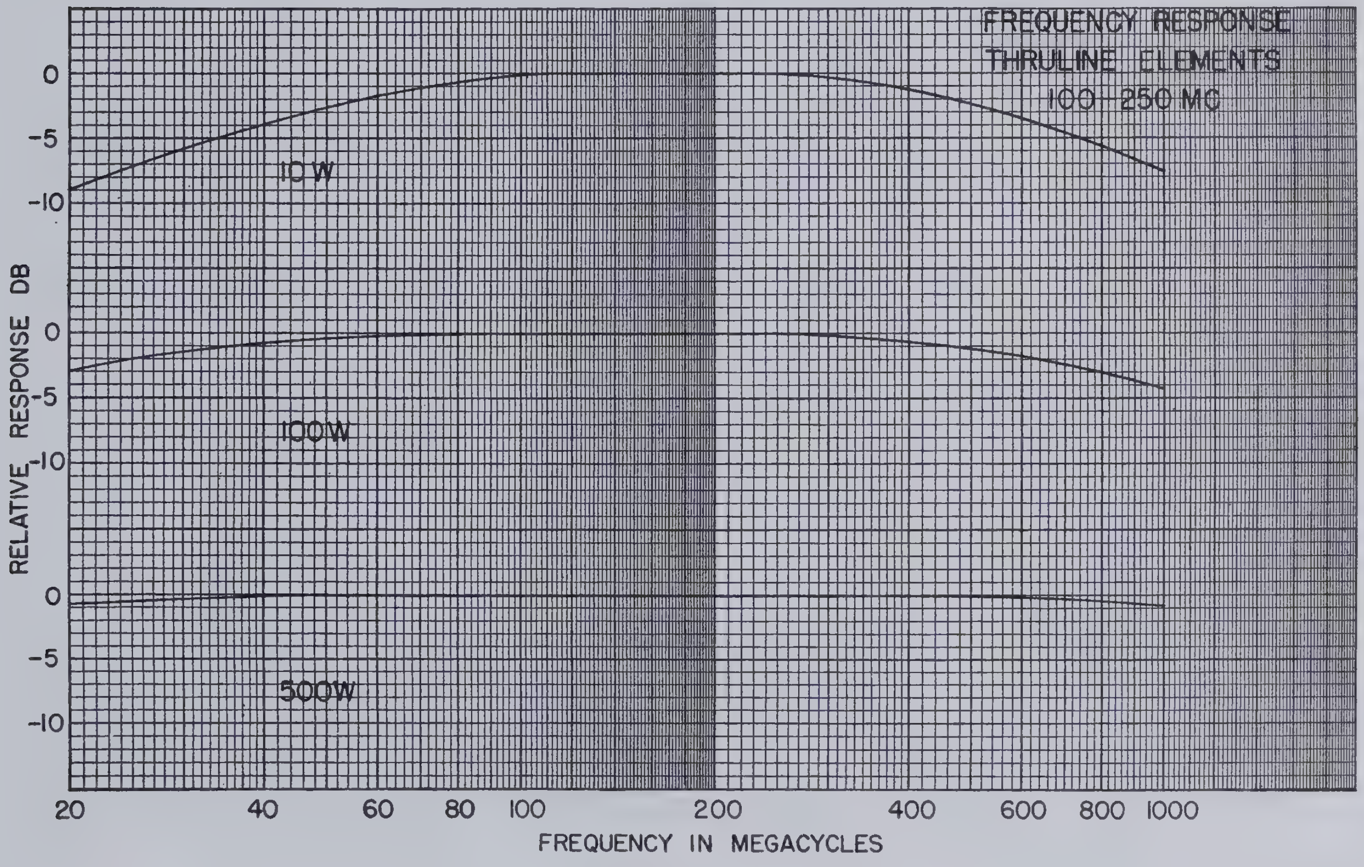
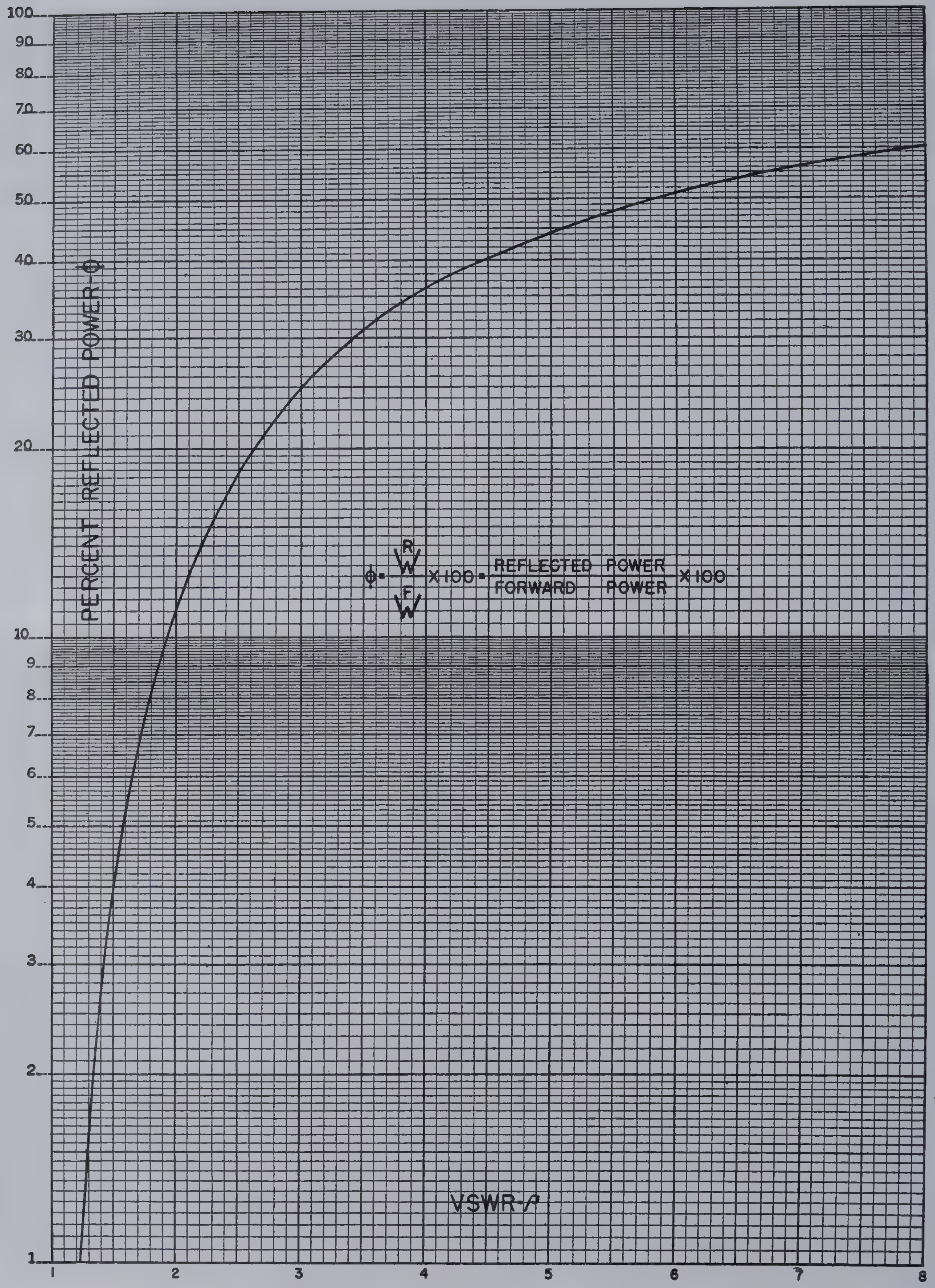
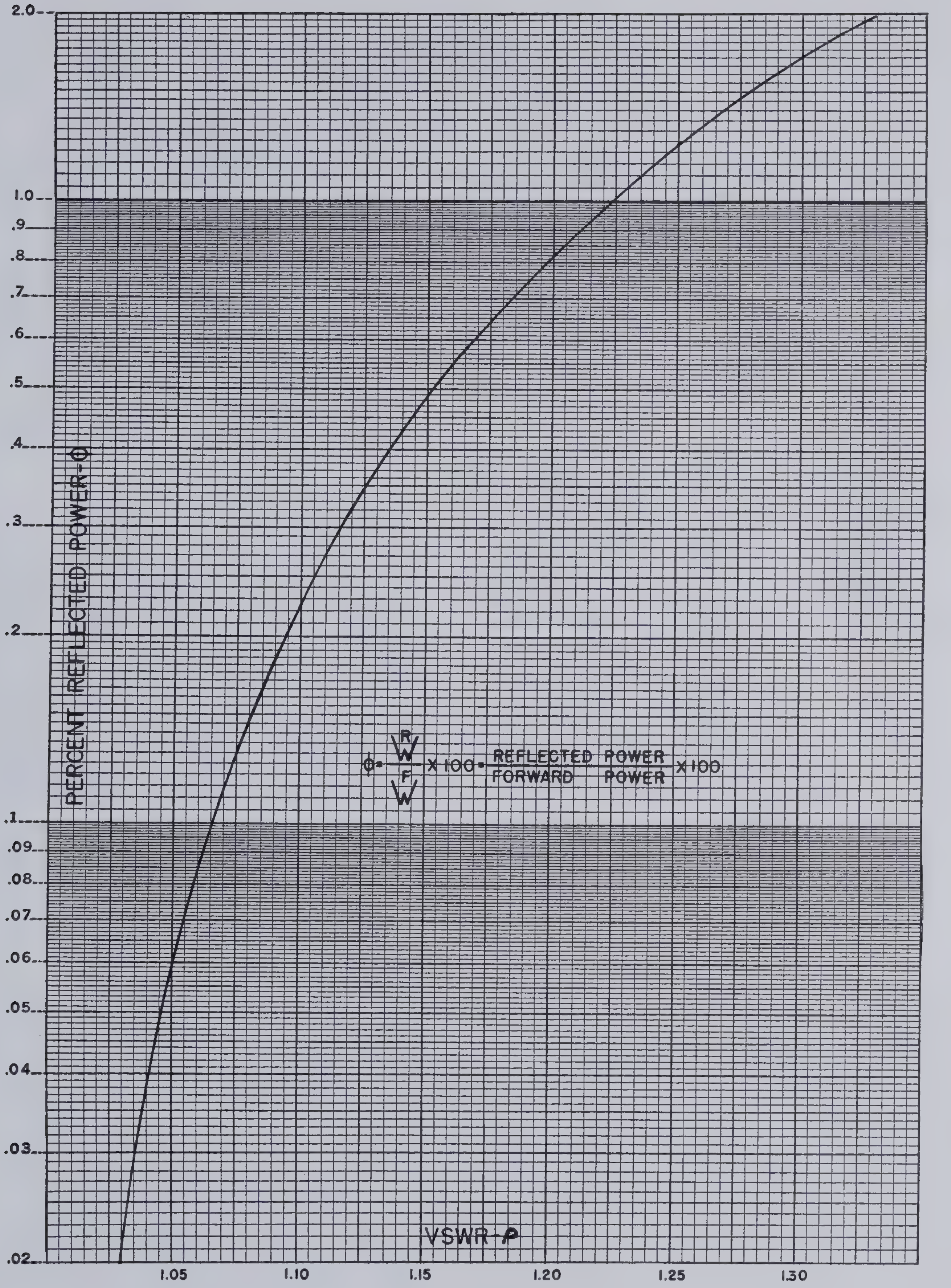


Fig. 4-2. Graph - Frequency Response



4-1b. Graph. - Percent Reflected Power vs. VSWR (1.0 to 8.0).



4-1a. Graph. - Percent Reflected Power vs. VSWR (1.0 to 1.3).

SECTION 4
OPERATION

1. GENERAL

The apparent features of the THRULINE equipment have been discussed in Section 1, GENERAL DESCRIPTION, and in the instructions of Section 3, INSTALLATION. Measurements are made by the insertion and operation of the plug-in elements previously mentioned.

The elements determine the power range to be read on the meter scale, and the major markings (viz. 50W, 100W, etc.) are the FULL SCALE POWER value for that element. Elements are also marked for FREQUENCY RANGE. The transmitter frequency must be within the band of the element used. Elements are available according to those identified in the table below.

See paragraph 4 of this chapter for frequency band flatness, and performance of the elements outside of stated frequencies. Elements for additional ranges (power or frequency) may be ordered without returning the THRULINE for calibration, since the r-f bodies and meters are standardized, and are designed for a wide range of coaxial transmission power values and frequencies.

ARROW on plug-in element indicates Sensitive DIRECTION, i.e., the direction of power flow which the meter will read. ARROW and REVERSE are directional terms used in reference to the THRULINE ELEMENT, and mean respectively the sensitive and null directions of the element. ROTATE ELEMENT to reverse the sensitive direction. FORWARD and REFLECTED are directional terms used in reference to the source - load circuit. Note that the transmitter may attach to either connector of the THRULINE. It makes no difference which external r-f connection is selected, since the elements are reversible and the r-f circuit is symmetrical end for end. Before taking readings be sure that the meter pointer has been properly zeroed under no-power conditions.

The THRULINE used with a TERMALINE resistor of proper power rating forms a highly useful absorption wattmeter. With ARROW set toward the load, it is unnecessary to reverse because reflected power may be neglected.

In cases where readings are being made when the meter unit is connected to an auxiliary r-f line section body, always remove any measuring element from the unused r-f line section. Otherwise, the d-c circuit will be unbalanced or shorted according to the arrow position of the other element, causing inaccurate or no reading on the meter.

2. LOAD POWER

Power delivered to (and dissipated in) a load is given by:

$$\overset{L}{W} = \text{Watts into Load} = \overset{F}{W} - \overset{R}{W}$$

i.e., where appreciable power is reflected, as with an antenna, it is necessary to subtract reflected from forward power to get load power. This correction is negligible (less than 1 percent) if the load is such as to have a VSWR of 1.2 or less. Good load resistors, such as our TERMALINES, will thus show negligible or unreadable reflected power.

VSWR scales, and their attendant controls, for setting the reference point, have been intentionally omitted from the THRULINE for two reasons:

(a) Why make something similar to a hypothetical d-c volt ohmmeter with control pots for the voltmeter multipliers? Even more complications arise when diodes at r-f are involved.

(b) Experience using the THRULINE on transmitter tune-up, antenna matching etc., i.e., on OPERATING PROBLEMS shows that the power ratio ϕ is no mean competitor, in practical usefulness, to the ratio ρ = VSWR.

TABLE 1—RANGE OF ELEMENT TYPES

STANDARD THRULINE ELEMENT TYPES									
TYPE	Frequency Band - Mcs	WATTS FULL SCALE							
		5	10	25	50	100	250	500	1000
H	2-30	-	-	-	50H	100H	250H	500H	1000H
A	25-60	5A	10A	25A	50A	100A	250A	500A	1000A
B	50-125	5B	10B	25B	50B	100B	250B	500B	1000B
C	100-250	5C	10C	25C	50C	100C	250C	500C	1000C
D	200-500	5D	10D	25D	50D	100D	250D	500D	1000D
E	400-1000	5E	10E	25E	50E	100E	250E	500E	1000E

1 and 2.5 watt element made on special order for narrow frequency ranges, except 2-30 mc ("H" Band)

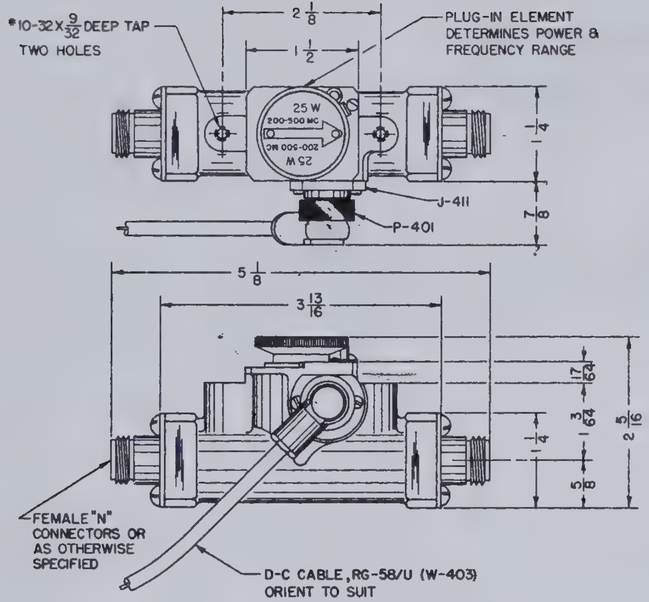


Fig. 3-2. Installation Drawing, R-F Line Section

2. REMOTE INSTALLATION

It is frequently advisable to mount the r-f section in a fixed location, particularly above 200 MC, to keep r-f lines short and to allow rigid connections without flexible cables. The standard meter cable, coiled within the housing, is 2-3/4 feet long. Longer meter cables are available on special order, 25 feet being a semi-stock length. As long as shielded cable is used (preferably RG-58/U), users may improvise their own extension cables. Additional interchangeable r-f bodies (Fig. 3-2) are available. It may be desirable to have two or more such bodies permanently installed in continuously operating equipment. In this case, one set of elements and one meter may be used to measure several r-f lines WITHOUT INTERRUPTION OF R-F LINES for insertion of the THRULINE.

If it is desired to panel mount the r-f line section, it blends very readily to this type of installation. A layout for the panel mount cutting is given in Fig. 3-3. The preferred panel thickness is 1/4 inch, but variations thicker or thinner will be acceptable. The use of a properly designed shim plate or of washers will make installation with thinner panels quite satisfactory. To simplify cable connections the r-f line section may be mounted in any convenient direction. Attach the r-f unit so that the finger catch is in the most accessible position.

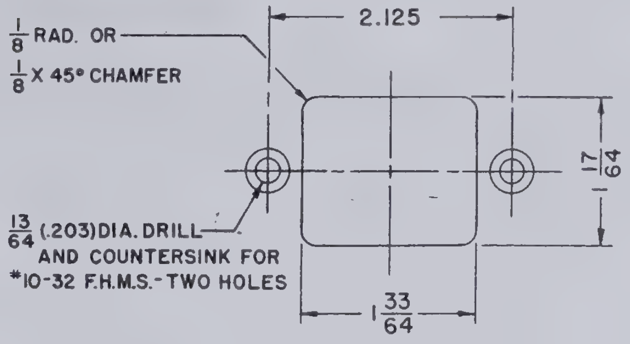


Fig. 3-3. Panel Cut for Mounting R-F Body

3. CONNECTIONS

The THRULINE is inserted in an r-f circuit with any suitable coaxial cable of 50-ohms impedance only. It is quite indifferent as to which respective side the power source and the load connections are made. If cables of other than 50-ohms impedance are used, mismatch will occur and introduce probably serious inaccuracies in the readings. We strongly urge the avoidance of this condition. Nevertheless, in the possible event of need, the calculation of results from same are discussed in Section 4, Para. 7.

The equipment is normally supplied with two female "N" type connectors. Connection is readily made with male "N" cable plugs. However, the following types of these quick-change connectors are now available:

Female "N"
Male "N"
Female "HN"
Male "HN"
Female "C"
Male "C"
Female UHF (SO-239)
Male UHF (PL-259)

Female "BNC"
Male "BNC"
Female "LC"
Male "LC"
Female "LT"
Male "LT"
7/8" EIA Air Line

These may be purchased from Bird Electronic Corp. as required. See Parts List, Section 6. Any of these above connectors can be changed readily by removing the #8-32 round head machine screws at each corner of the square flanges, and pulling straight outwards, carefully disengaging the spring fingers of the center conductor. Reverse this procedure to attach the connectors.

SECTION 3
INSTALLATION

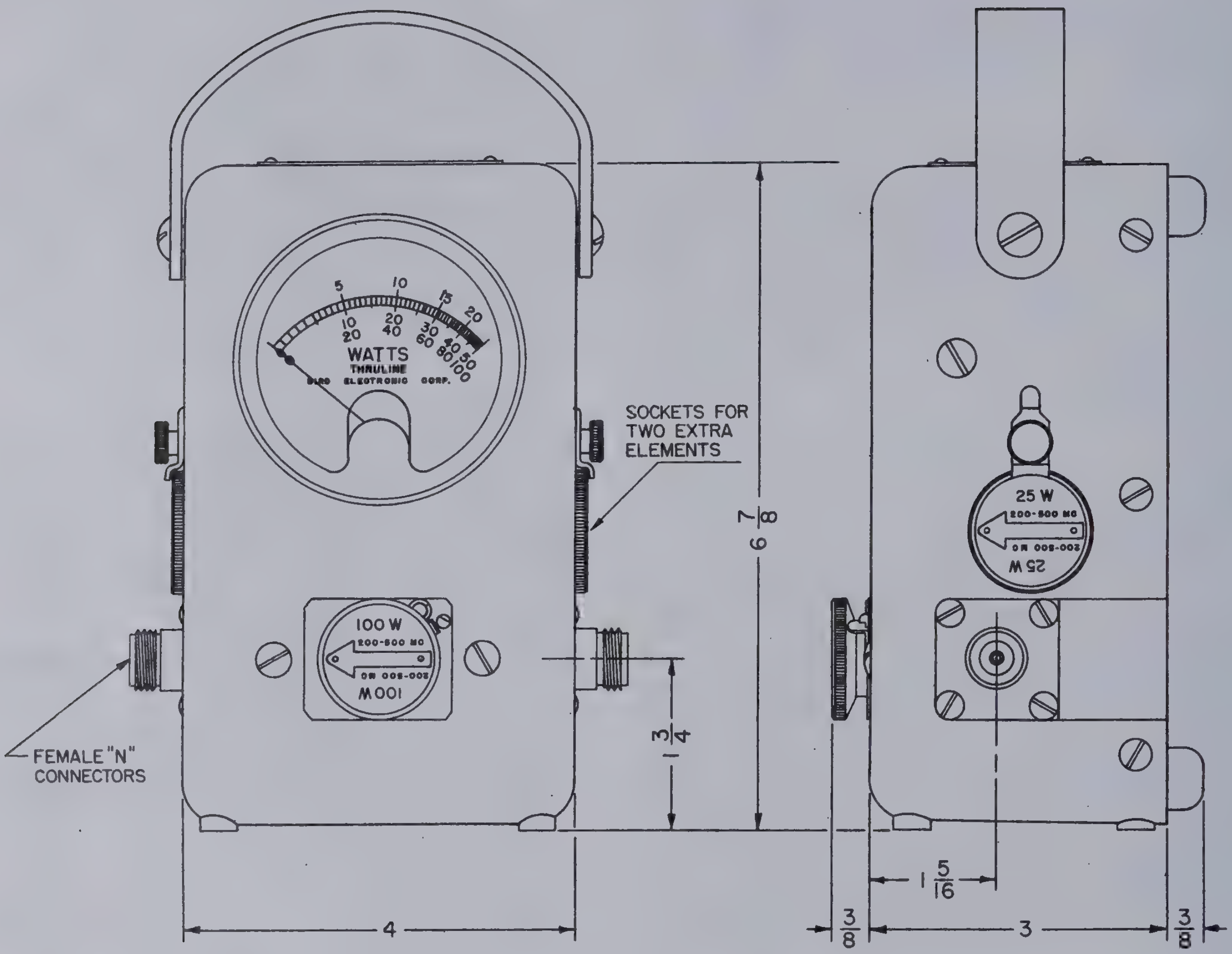


Fig. 3-1. Outline Drawing, Model 43 THRULINE

1. PORTABILITY

The Model 43 is essentially a portable instrument, and the housing is not specifically designed for attached mounting, see Outline Drawing, Fig. 3-1. A strap is provided for carrying purposes. Special Precaution - while transporting the THRULINE, it is best to insert a Plug-In Element and point the ARROW UPWARDS. This will shunt the meter connection circuit and serve to actively dampen needle action during handling or shipping. Also, at these times, secure the spare Plug-In Elements firmly by use of the thumbscrews for each socket. A fall could disrupt the calibration of the Elements, and they should be handled with reasonable care at all times.

DO NOT DROP the THRULINE or subject it to hard blows. The microammeter is shock mounted in the housing to protect it against ordinary hazards, but its delicate mechanism may be damaged by severe impact.

The r-f line section, Fig. 3-2, may be removed from the housing for use elsewhere than in the meter housing. This may be accomplished by unscrewing the six #8-32 flat head machine screws around the back (three on each side). Then grasp the back cover by the side filler tabs and pull directly backwards. The entire back assembly will come off, with the speed nuts remaining attached. Now the line section may be loosened by removing the two #10-32 oval head machine screws on the front of the housing, right in line with the r-f section axis. It may now be slid directly backwards right out of the housing.

SECTION 2
THEORY OF OPERATION

1. TRAVELLING WAVE VIEWPOINT

It is simplest to visualize the THRULINE idea from the TRAVELLING WAVE viewpoint on transmission lines, which shows that the voltages, currents, standing waves, etc., on any uniform section of line are the resultants of two travelling waves:

FORWARD WAVE travels (and its power flows) from source to load, has r-f voltage E and current I in phase, with $E/I = Z_0$

REFLECTED WAVE originates by reflection at the load, travels (and its power flows) from load to source and also has its voltage $\mathcal{E}$ and current $\mathcal{I}$ in phase, with $\mathcal{E}/\mathcal{I} = Z_0$

Note that each component wave is mathematically simple, and is completely described by a single figure for power, for instance:

$$\backslash\overset{F}{W}/ = \text{Watts Forward} = E^2/Z_0 = I^2Z_0 = EI$$

$$\backslash\overset{R}{W}/ = \text{Watts Reflected} = \mathcal{E}^2/Z_0 = \mathcal{I}^2Z_0 = \mathcal{E}\mathcal{I}$$

Z_0 is the characteristic impedance of the uniform line, and simplifies things by being a pure resistance, usually 50 ohms, for useful lines. The r-f main line circuit of the THRULINE is a short uniform section of air line, whose Z_0 is exactly 50 ohms, and in which accurate measurements may be made.

2. COUPLING CIRCUIT

The coupling circuit which is sampling the travelling waves is in the plug-in element. The circuitry of the element and its relationship to the other components of the THRULINE are shown in the schematic diagram, Fig. 2-1. Energy will be produced in the coupling circuit of the element both by mutual inductance and capacitance from the travelling r-f waves of the line section. The inductive currents will of course flow according to the direction of the travelling waves producing them. The capacitative portion of these currents is naturally independent of the direction of the travelling waves. Therefore, assuming that the element remains stationary, it is apparent that the current produced from the waves of one direction will add in phase, while those of the opposite direction will subtract in phase. The additive or "ARROW" direction is of course assigned to the forward wave, while the element is so designed and carefully balanced that the currents produced from the reverse wave will cancel each other almost completely. The resultant is a directivity always higher than 35db, which means that the element is highly insensitive (nulled) to the "REVERSE" direction wave. Being highly directional, the THRULINE ELEMENT is sensitive, at one setting, only to one of the travelling waves which produce standing waves by interference. THRULINE measurements are therefore independent of position along standing waves. It may be said that the THRULINE doesn't know, doesn't care and doesn't need to care where it is along a standing wave.

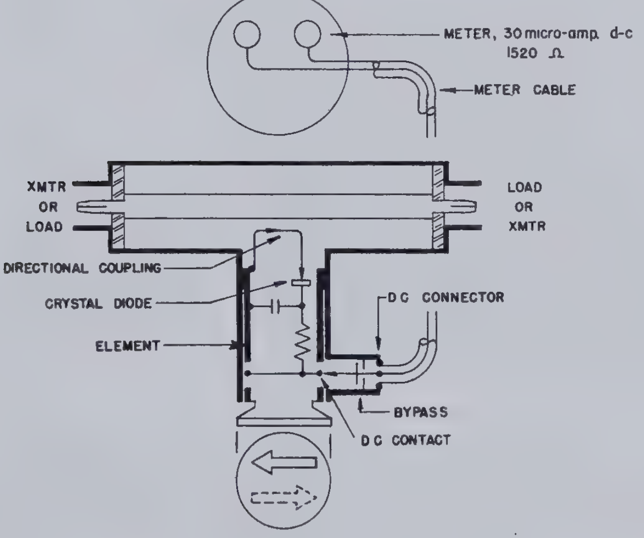


Fig. 2-1. Schematic Diagram

3. STANDING WAVE RATIO vs. REFLECTED/FORWARD POWER RATIO

As mentioned above, the THRULINE uses a TRAVELLING WAVE viewpoint to measure most of the significant facts about transmission line operation. The STANDING WAVE viewpoint is another, quite elaborately developed, both mathematically and in existing instruments, which is widely used. Relationships between these viewpoints and their mathematical systems are given in most high frequency texts.

It is believed here that the more widespread use of the standing wave viewpoint and mathematics can be traced to the earlier development of slotted lines as exploring tools with which quantitative figures are obtained from the line. The slotted line is a standing wave instrument in fact, and use of it emphasizes the standing wave viewpoint.

There is not much question that slotted lines are too long, too expensive if good, not portable, and are slow and exacting in operation, these objections increasing rapidly as frequency drops below 1000 MC. The THRULINE is surprisingly quick, convenient and accurate by comparison. With the exception of reflection phase angle (distance, load to minimum) it tells everything a slotted line will tell.

SECTION 1
GENERAL DESCRIPTION

1. PURPOSE AND APPLICATION

The Model 43 THRULINE WATTMETER is a directional r-f wattmeter, which measures power flow and load match in coaxial lines. It is for use with CW, AM, FM, and TV modulation envelopes, but is not for use on pulsed transmitters. Model 43 is designed for 50-ohm application, the insertion VSWR being less than 1.05 for frequencies up to 1000 MC in a standard 50-ohm circuit. The meter is direct reading (30ua d-c full scale), expanded down-scale for easy reading, and is graduated 25, 50, and 100 watts full scale. Further characteristics of the unit may be found in the summary sheet on page A.

2. DESCRIPTION (See Fig. 1-1)

The THRULINE WATTMETER is a portable unit contained in a die cast aluminum housing, with removable formed metal enclosure at the rear. The unit includes a leather carrying strap, four rubber bumper feet on the base, and four rubber bumpers on the back for use in standing or flat-laying applications. For further mechanical protection the microammeter is shock mounted between a hollow rubber back-up ring and three stem bumpers on the front flange of the meter. On the lower front face of the meter there is a slotted adjustment screw to zero the pointer. Below the meter opening is a rectangular aperture, at the front, through which projects only the top face of the line section casting, with the measuring element socket in the center.

A cable, entirely shielded against stray or r-f interference, connects the microammeter to the d-c jack attached to the side of the line section casting. This cable is nearly three feet in length, and permits the r-f line section to be removed from the housing. Connections to the meter may be readily maintained for any installations outside of the housing. Through the use of extra r-f bodies, permanent auxiliary installations may be maintained. See Section 3, INSTALLATIONS.

The d-c jack assembly has a filter capacitor nested inside, which shunts across the meter cable circuit. This more fully protects meter readings against the adverse effect of any stray r-f energy existant in the plug-in element. The d-c jack mounts a phosphor bronze spring finger. This opens into the plug-in element socket through a lateral clearance hole in the line section. The finger has a small silver button near its end, which mates with the contacts on the inserted elements. The line section is a silver plated brass casting, precision produced to provide unimpaired impedance of the r-f coaxial line in which it is inserted. For additional mechanical support the ends of the line section are machined to accurate size and nested in mating slots in the side wall of the housing. The r-f connectors at each end are of a quick-change type, being fastened down only by the four screws of the respective mounting flanges. The housing does not interfere with any connector changes.

To make measurements, the cylindrically shaped plug-in elements are inserted in the socket of the line section. A small catch in the upper right hand corner of the casting face presses on the shoulder of the plug-in element body, thereby maintaining the element in steady alignment with an assured bottom contact, to provide the most consistent electrical operation. The plug-in element has its terminals on diametrically opposite sides of the body, so that pick-up is made in either direction. The contacts on the plug-in element make connection with the d-c pick-up button only when the plug-in element is in the precise forward or reverse position. The small index pin on the element must be on the lower level of the casting face and against its respective stop.

The meter scale, as described above, is read according to the full scale rating stamped on the cap of the plug-in measuring element. These elements also fall in five frequency band groups, more fully described in Section 4, Paragraph 1.

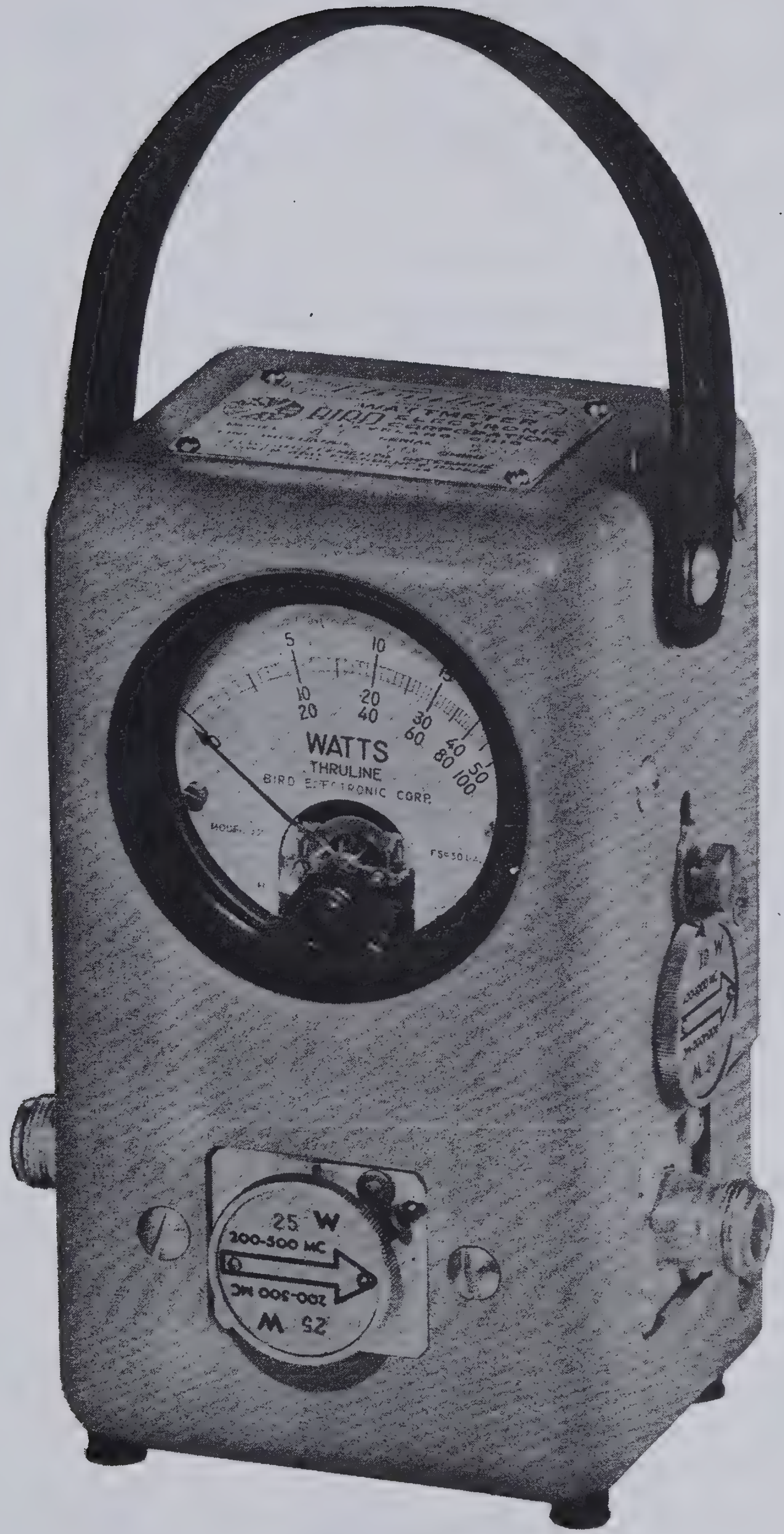


Fig. 1-1. View of Model 43 THRULINE

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Measures - R-F Power - 10W to 500W Full Scale Direct Reading in Watts, Frequency Range 25 - 1000 MC in five element types, See Table I, Section 4.

Insertion VSWR - Less than 1.05 VSWR up to 1000 MC

Accuracy - ±5% of Full Scale Power

Dimensions - Basic Overall 7"lg x 4"w x 3"h

Weight - 4 Pounds

Connectors - Female and Male "N"
Female and Male "HN"
Female and Male "C"
Female UHF (SO 239)

Not supplied on regular orders

2 Female "N" Connectors standard with equipment, unless otherwise specified.

INSTRUCTION BOOK

for the

Thruline

WATTMETER

MODEL 43

BIRD ELECTRONIC CORP.
CLEVELAND, OHIO

INSTRUCTION BOOK

for the

Thruline

WATTMETER

MODEL 43

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INSTRUCTION MANUAL for

THRULINE®
model 43
RF Directional Wattmeter

INSTRUCTION BOOK

for the

Thruline

WATTMETER

MODEL 43

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SUMMARY SHEET

Circuit - 50-ohm impedance - THRULINE

Measures - RF Power - 5W to 5000W Full Scale Direct Reading in Watts, Frequency Range 2 - 1000 MHz in Six Std. Element types, See Table I, Section 4.

Insertion VSWR - Less than 1.05 VSWR up to 1000 MHz

Accuracy - ±5% of Full Scale Power

Dimensions - Basic Overall 7"lg x 4"w x 3"h

Weight - 4 Pounds

Connectors - Female and Male "N"

Female and Male "HN"

Female and Male "C"

Most std. 50-ohm AN types

Not supplied on regular orders

2 Female "N" Connectors standard with equipment, unless otherwise specified.

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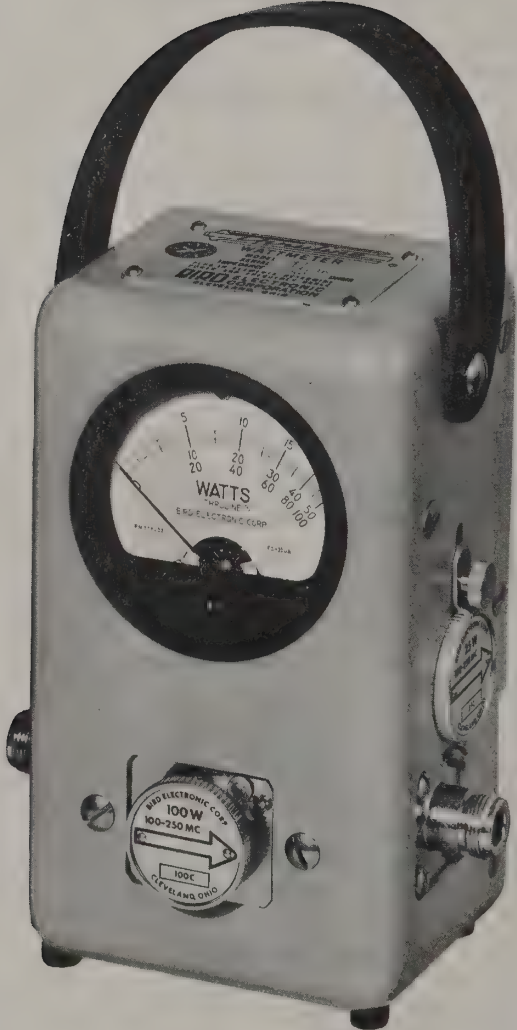


Fig. 1-1. Model 43 THRULINE

SECTION 1
GENERAL DESCRIPTION

1. PURPOSE AND APPLICATION

The Model 43 THRULINE Wattmeter is an insertion type RF wattmeter, designed to measure power flow and load match in 50-ohm coaxial transmission lines. It is intended for use on CW, AM, FM, and TV modulation envelopes, but not pulsed modes. The Model 43, when used in 50-ohm applications, has an insertion VSWR of less than 1.05:1 up to a frequency of 1000 MHz. The meter is direct reading in watts, expanded down scale for easy reading, and is graduated 25, 50, and 100 watts full scale. The power ranges used are determined by the Plug-In Elements, which fall in ten frequency band groups covering from 2 to 2300 MHz plus additional special Elements in various power and frequency ranges (see Section 4). Further characteristics may be found in the Summary Sheet on page A.

2. DESCRIPTION

The Model 43 THRULINE, Figure 1-1, is a portable unit contained in a die cast aluminum housing, with a formed metal enclosure on the back which is easily removed. Included with the unit is a leather carrying strap, four rubber shock feet on the base, and four rubber bumpers on the back, which allow the Model 43 to stand or lie flat when used. For additional protection, the microammeter is specially shock mounted. A slotted screw is provided on the lower front face of the meter for zeroing the pointer. Below the meter, the RF line section face protrudes slightly from the wattmeter housing with the Plug-In Element socket in the center.

A shielded cable connects the microammeter to the dc jack which is attached to the side of the RF line section casting. This cable, nearly three feet long, permits removal of the RF line section from the Wattmeter housing. Meter connections may be maintained with any installations outside of the housing. This permits permanent additional installations to be made. See Section 3, INSTALLATION.

Inside the dc jack assembly, there is a filter capacitor which shunts the meter circuit to prevent mis-readings caused by stray RF energy existing in the Plug-In Element. Mounted on the dc jack is a phosphor bronze spring finger, which protrudes through a lateral hole and into the Plug-In Element socket of the RF line section. The finger has a button on its end which mates with the contacts of the Plug-In Element. The nickel plated brass RF line section is precision made to provide the best possible impedance match to the coaxial RF transmission line in which the Model 43 is inserted. The ends of the line section are nested in mating slots to provide additional mechanical support.

At each end of the line section are Bird Quick-Change type RF connectors, which may be quickly interchanged with any other Bird "QC" connector by removing the four screws on the mounting flanges. The Wattmeter housing does not interfere with any connector changes.

To make measurements, the cylindrical shaped Plug-In Element is inserted into the line section socket and rotated against one stop. A small catch in the upper right hand corner of the casting face presses on the shoulder of the Plug-In Element to keep it in proper alignment and assure a good contact with the dc jack and between the lower edge of the Element and line section body. On diametrically opposite sides of the Plug-In Element body are contacts to provide dc pick-up in either direction. These contacts make connection with the spring finger of the dc jack only when the Plug-In Element is in the precise forward or reverse position, and with the index pin on the Element on the lower level of the line section casting face against its respective stop.

SECTION 2
THEORY OF OPERATION

1. TRAVELLING WAVE VIEWPOINT

The best way to visualize the THRULINE idea is from the TRAVELLING WAVE viewpoint on transmission lines, which illustrates that the voltages, currents, standing waves, etc., on any uniform line section are the result of two travelling waves:

FORWARD WAVE travels (and its power flows) from source to load, and has RF voltage E and current I in phase, with $E/I = Z_O$.

REFLECTED WAVE originates by reflection at the load, travels (and its power flows) from the load to source and also has an RF voltage $\mathcal{E}$ and current $\mathcal{I}$ in phase, with $\mathcal{E}/\mathcal{I} = Z_o$.

Note that each component wave is mathematically simple, and is completely described by a single figure for power, for instance:

$\overset{F}{W}$ = Watts Forward = $E^2/Z_O = I^2 Z_O = EI$

$\overset{R}{W}$ = Watts Reverse = $\mathcal{E}^2/Z_o = \mathcal{I}^2 Z_o = \mathcal{E}\mathcal{I}$

Z_O is the characteristic impedance of the uniform line, and simplifies matters by being a pure resistance, usually 50 ohms, for useful lines. The main RF circuit of the THRULINE is a short piece of uniform air type line section, whose Z_O is a very accurate 50 ohms, in which correct measurements may be made.

2. COUPLING CIRCUIT

The coupling circuit which samples the travelling waves is in the Plug-In Element. The circuitry of the Element and its relationship to the other components of the THRULINE are illustrated in the schematic diagram, Figure 2-1. Energy will be produced in the coupling circuit of the Element by both mutual inductance and capacitance from the travelling RF waves of the line section. The inductive currents will, of course, flow according to the direction of the travelling waves producing them. The capacitive portion of these currents is naturally independent of the direction of the travelling waves. Therefore, assuming that the Plug-In Element remains stationary, it is apparent that the coupling currents produced from the waves of one direction will add in phase, and those produced from waves of the opposite direction will accordingly subtract in phase. The additive or "ARROW" direction is, of course, assigned to the forward wave.

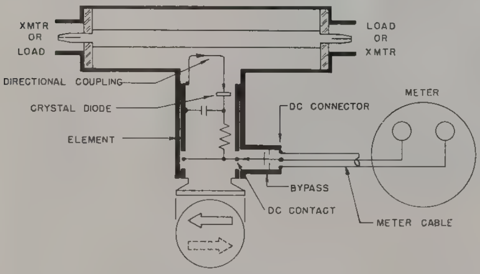


Fig. 2-1. Schematic Diagram

The electrical values of the Element circuits are carefully balanced and so designed that the current produced from the reverse wave will cancel the other almost completely. The resultant is a directivity always higher than 30 dB, which means that the Element is highly insensitive (nulled) to the "REVERSE" direction wave. Being highly directional, the THRULINE Element is sensitive (at one setting) only to one of the travelling waves which produces standing waves by interference. THRULINE measurements are therefore independent of position along standing waves. It may be said that the THRULINE doesn't know, doesn't care, and doesn't need to care where it is along a standing wave.

3. STANDING WAVE RATIO vs. REFLECTED/FORWARD POWER RATIO

As mentioned above, the THRULINE technique uses the TRAVELLING WAVE viewpoint to measure most of the outstanding facts about transmission line operation. Another widely used and related viewpoint, is the STANDING WAVE, which is quite elaborately developed both mathematically and in existing equipment. This technique can be traced to the early development of slotted lines as tools of exploration.

The slotted line is a standing wave instrument, and emphasizes this viewpoint. However, the slotted line is too long, too expensive if good, not portable, and slow in operation. These objections increase rapidly as the frequency drops below 1000 MHz. Whereas the THRULINE is surprisingly quick, convenient, and accurate by comparison. With the exception of phase angle reflection (distance, load to minimum) it tells everything a slotted line will.

The relationships between TRAVELLING WAVES and STANDING WAVE viewpoints are given in most high frequency textbooks.

SECTION 3
INSTALLATION

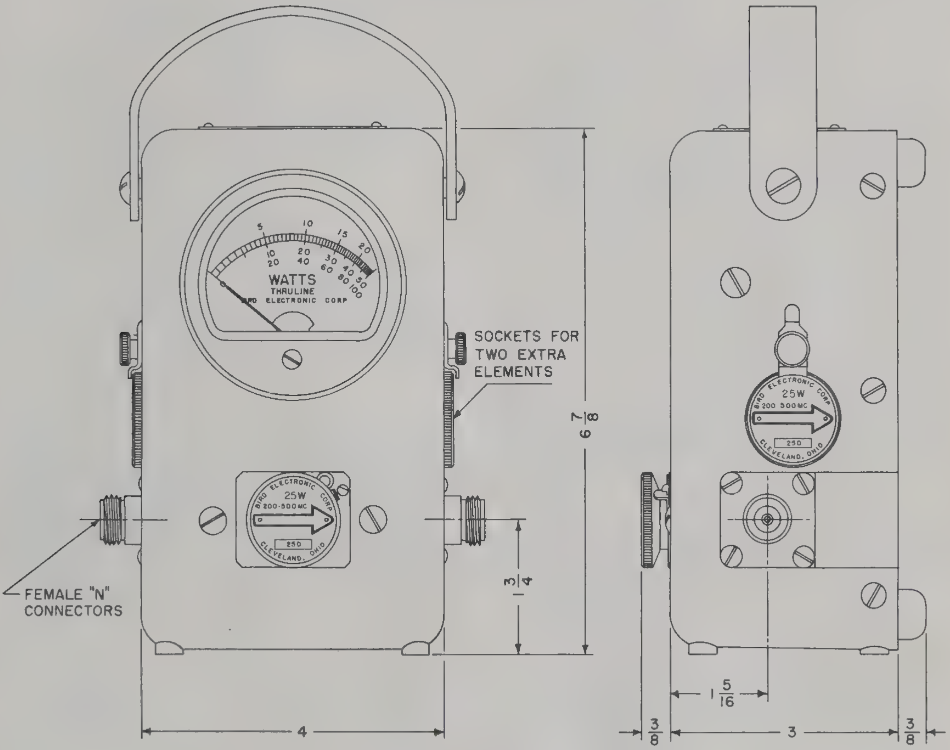


Fig. 3-1. Outline Drawing, Model 43 THRULINE

1. PORTABILITY

The Model 43 is a portable instrument, and the housing is not designed for fixed mounting (see Outline Drawing, Figure 3-1). A strap is provided for carrying purposes.

While transporting the THRULINE, it is best to insert a Plug-In Element, secure with the catch, and point the ARROW upwards. This will shunt the meter circuit and serve to protect the meter by dampening needle action during handling or shipping. Also, secure the spare Plug-In Elements in their receptacles with the thumbscrew and clamp. Handle the Plug-In Elements with care at all times. Calibration could be disturbed if they are dropped.

CAUTION

Do not drop the THRULINE or its Elements or subject them to hard blows. The microammeter is shock mounted in the wattmeter housing, but its delicate mechanism may be damaged by severe impact.

2. CONNECTIONS

Insert the Model 43 THRULINE in coaxial transmission lines of 50 ohms nominal impedance. It is indifferent to which respective side the power source and the load connections are made. If cables other than 50 ohms are used, a mismatch will occur causing probable serious inaccuracies in readings. However, if a mismatch cannot be avoided, the results may be calculated per paragraph 7 of Section 4. We strongly urge that you avoid this condition.

The Model 43 is normally supplied with two Female N-Type connectors which are of the Bird Quick-Change design. Other "QC" connectors are available as listed:

Male N
Female HN
Male HN
Female C
Male C
Female UHF
Male UHF
7/8" EIA Air Line
Female BNC
Male BNC
Female LC
Male LC
Female LT
Male LT
Female TNC
Male TNC

These may be purchased from Bird Electronic Corp., as required. See Section 6, Parts List.

The above connectors are quickly changed by removing the four #8-32 round head machine screws from the corners of the connector flange, and pull straight out. Reverse this procedure to attach connector, making sure the center contact pin aligns properly with the socket.

3. REMOTE INSTALLATION

The RF line section can be removed from the meter housing for remote installation. To remove the line section from its housing:

a. Unscrew the six #8-32 flat head machine screws holding the back cover.

b. Grasp the cover by the side filler tabs and pull directly backwards. The back cover assembly will come off with the speed nuts remaining attached.

c. Remove the two #10-32 oval head machine screws on the front of the housing.

d. Slide the line section backwards out of the housing. Do not loosen the two oval head screws on the sides of the housing in line with the meter. These hold the meter supporting shock ring in place.

e. Substitute the cable which attaches the line section to the meter with a sufficient length of cable to make the remote installation.

f. To replace the RF line section, reverse the above procedure.

It may be desirable to have two or more line sections permanently installed in continuous operating equipment. In this case, one set of Elements and one meter may be used to measure several RF transmission lines WITHOUT INTERRUPTION OF RF LINES for insertion of the THRULINE. Additional RF line sections (Figure 3-2) are available.

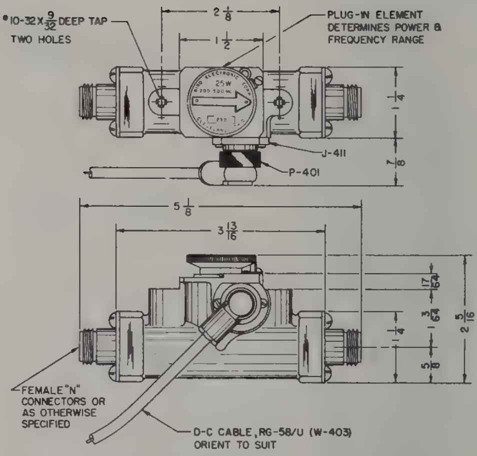

*10-32 X 9/32 DEEP TAP
TWO HOLES
2 1/8
1 1/2
PLUG-IN ELEMENT DETERMINES POWER & FREQUENCY RANGE
1 1/4
7/8
J-411
P-401
5 1/8
3 13/16
17/64
1 3/64
2 5/16
1 1/4
5/8
FEMALE "N" CONNECTORS OR AS OTHERWISE SPECIFIED
D-C CABLE, RG-58/U (W-403) ORIENT TO SUIT

Fig. 3-2. Installation Drawing, RF Line Section

The RF Line Section of the Model 43 blends very readily to panel type mounting. A layout for the panel mount cut is given in Figure 3-3. The thickness of the panel should be about 1/4 inch. On panels less than this, build up the thickness with pads or washers to achieve a flush-face mounting. Cable connections are simplified because the RF line section may be mounted in any convenient direction. Attach the line section so that the finger catch is in the most accessible position.

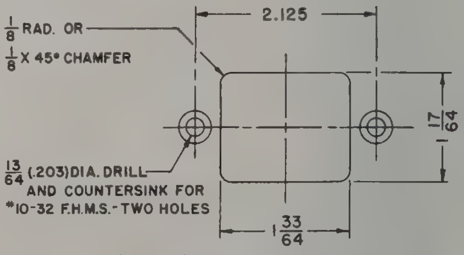

1/8 RAD. OR
1/8 X 45° CHAMFER
2.125
1 17/64
13/64 (.203) DIA. DRILL AND COUNTERSINK FOR *10-32 F.H.M.S.-TWO HOLES
1 33/64

Fig. 3-3. Panel Cut for Mounting RF Body

SECTION 4
OPERATION

1. GENERAL

The apparent features of the THRULINE equipment have been discussed in Section 1, GENERAL DESCRIPTION, and in the instructions of Section 3, INSTALLATION. Measurements are made by the insertion and operation of the Plug-In Elements previously mentioned.

The Elements determine the power range to be read on the meter scale, and the major markings (viz. 50W, 100W, etc.) are the FULL SCALE POWER value for that Element. Elements are also marked for FREQUENCY RANGE. The transmitter frequency must be within the band of the Element used. Elements are available according to those identified in the tables on page 4-6.

See paragraph 6 of this chapter for frequency band flatness, and performance of the Elements outside of stated frequencies. Elements for additional ranges (power or frequency) may be ordered without returning the THRULINE for calibration, since the RF bodies and meters are standardized, and are designed for a wide range of coaxial transmission power values and frequencies.

ARROW on Plug-In Element indicates Sensitive DIRECTION, i.e., the direction of power flow which the meter will read. ARROW and REVERSE are directional terms used in reference to the THRULINE ELEMENT, and mean respectively the sensitive and null directions of the Element. ROTATE ELEMENT to reverse the sensitive direction. FORWARD and REFLECTED are directional terms used in reference to the source - load circuit. Note that the transmitter may attach to either connector of the THRULINE. It makes no difference which external RF connection is selected, since the Elements are reversible and the RF circuit is symmetrical end for end. Before taking readings be sure that the meter pointer has been properly zeroed under no-power conditions.

The THRULINE used with a TERMALINE resistor of proper power rating forms a highly useful absorption wattmeter. With ARROW set toward the load, it is unnecessary to reverse because reflected power may be neglected.

In cases where readings are being made when the meter unit is connected to an auxiliary RF line section body, always remove any measuring Element from the unused RF line section. Otherwise, the dc circuit will be unbalanced or shorted according to the arrow position of the other Element, causing inaccurate or no reading on the meter.

2. LOAD POWER

Power delivered to (and dissipated in) a load is given by:

$$\overset{L}{W} = \text{Watts into Load} = \overset{F}{W} - \overset{R}{W}$$

i.e., where appreciable power is reflected, as with an antenna, it is necessary to subtract reflected from forward power to get load power. This correction is negligible (less than 1 percent) if the load is such as to have a VSWR of 1.2 or less. Good load resistors, such as our TERMALINES, will thus show negligible or unreadable reflected power.

VSWR scales, and their attendant controls, for setting the reference point, have been intentionally omitted from the THRULINE for two reasons:

(a) Why make something similar to a hypothetical dc volt ohmmeter with control pots for the voltmeter multipliers? Even more complications arise when diodes at RF are involved.

(b) Experience using the THRULINE on transmitter tune-up, antenna matching etc., i.e., on OPERATING PROBLEMS shows that the power ratio ϕ is no mean competitor, in practical usefulness, to the ratio ρ = VSWR.

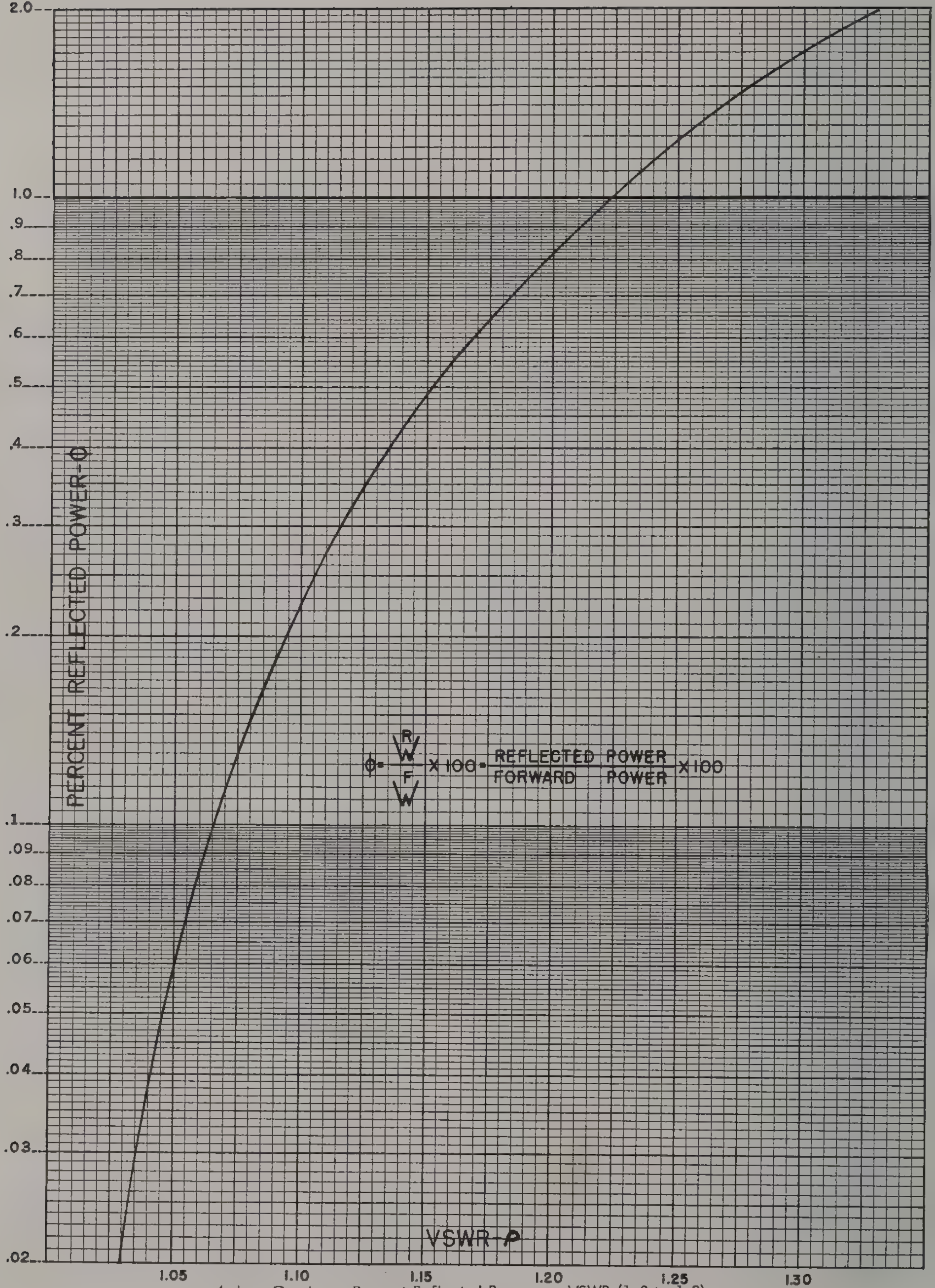
A trial is suggested for a few days — forget VSWR and try thinking in terms of $\phi = \overset{R}{W} / \overset{F}{W}$ when the THRULINE is used. It will be noted that, even without bothering to calculate the ratio exactly, the two meter readings $\overset{R}{W}$ and $\overset{F}{W}$ give an automatic mental impression which pictures the situation. Thus, in an antenna matching problem, the main thing usually is to minimize $\overset{R}{W}$, and anything done experimentally to this end is directly indicated when the THRULINE is in the reflected position. Furthermore, the ratio of readings, only mentally evaluated, is a reliable guide to the significance of the remaining reflected power.

3. GRAPH—ρ VS. ϕ AND ITS SIGNIFICANCE

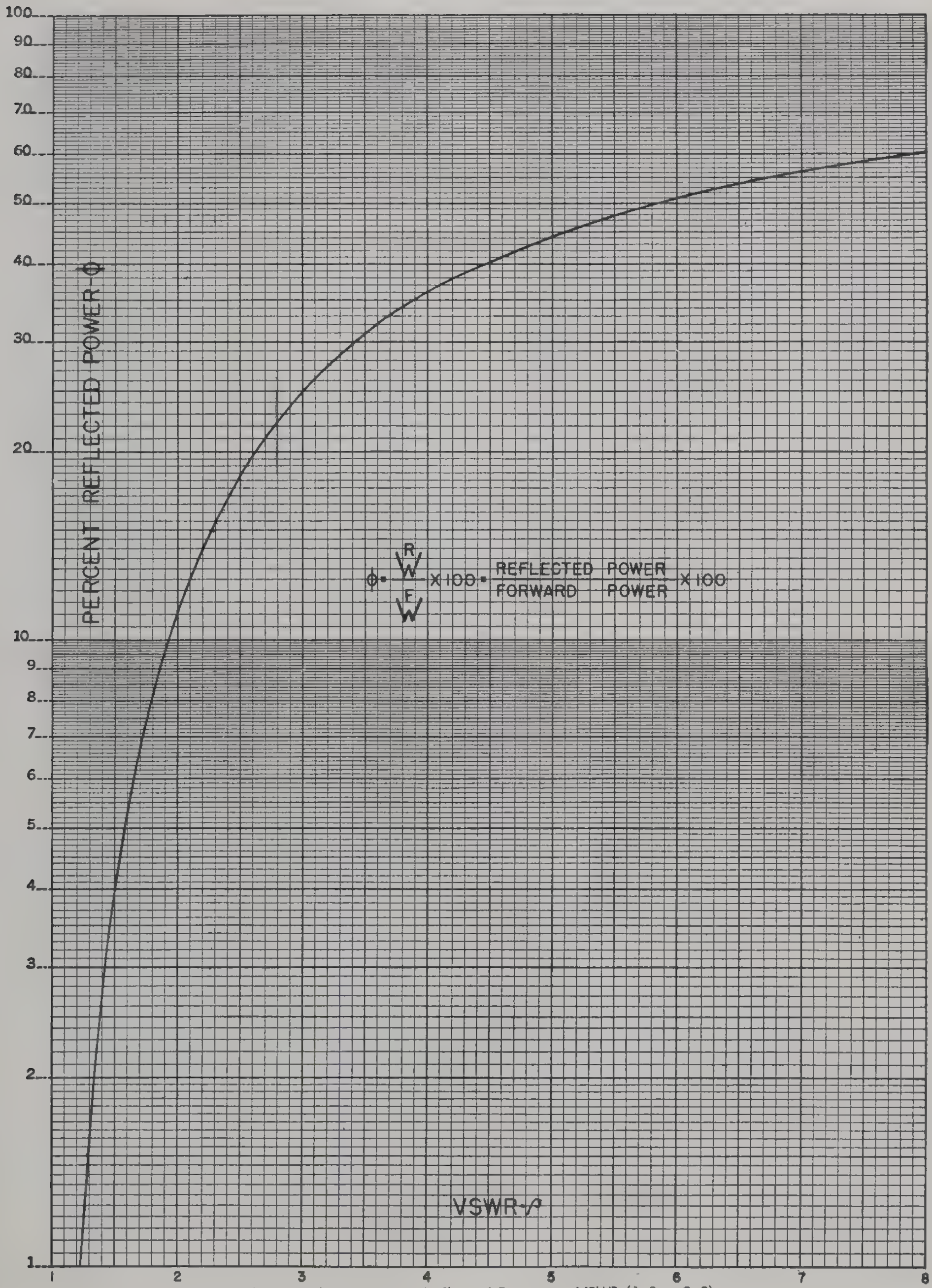
Since there are definite simple relationships

$$\rho = \frac{1+\sqrt{\phi}}{1-\sqrt{\phi}} \text{ and } \phi = \left[\frac{\rho-1}{\rho+1}\right]^2 \text{ where } \rho = \text{VSWR and } \phi = \frac{\overset{R}{W}}{\overset{F}{W}}$$

between standing wave ratio ρ and the reflected/forward power ratio ϕ indicated by the THRULINE, the latter may be conveniently used to measure VSWR. The relationship is given in Fig. 4-1a and b.



4-1a. Graph. — Percent Reflected Power vs. VSWR (1.0 to 1.3).



4-1b. Graph. — Percent Reflected Power vs. VSWR (1.0 to 8.0).

Note, that around Ø = 10%, below which $\overset{R}{W}$ will appear insignificant and become hard to read, you are close to the commonly accepted lower limit ρ = 2, below which improved antenna match becomes less and less worthwhile in many systems. Experimentally, using the THRULINE, it is readily shown that minimizing Ø below 10% produces little gain in $\overset{L}{W}$. TV transmitter antenna lines, and VHF Omni-range transmitters, are among systems requiring much lower levels of reflected power for reasons other than simple power transmission. Note also in Fig. 4-1a, the very small level of reflected power, Ø = .06 percent, corresponding to ρ = 1.05. With a single Element, detection of reflected power is possible down to about Ø = 1 percent, ρ = 1.2; if $\overset{F}{W}$ approaches full scale, measurement is possible down to about Ø = 5 percent, ρ = 1.5.

LOW-REFLECTION MEASUREMENTS may be extended below this with two Elements. Say 80 watts are available, and you have 100 watt and 10 watt Elements.

Measure $\overset{F}{W}$ with the 100 watt Element. Remove 100 W Element and insert 10 watt Element.

CAUTION: 10 watt Element must be ONLY in the REFLECTED direction. ARROW toward TRANSMITTER. Insert and remove ONLY this way.

Now read $\overset{R}{W}$ on the 10 watt Element.

SPECIAL NOTE

DON'T ROTATE 10 watt Element while TRANSMITTER is on. Always use great care with LOW SCALE Elements on HIGH power RF lines. Inadvertent exposure of these Elements to too much FORWARD or even too high reflected power may permanently damage the measuring Element or the microammeter.

In this case, measurement down to at least .5 watt reflected is possible which means to

Ø = $\frac{.5}{80}$, say .6 percent, or to about ρ = 1.16

and detection of reflections is possible down to about .1 watt,

Ø = $\frac{.1}{80}$ = .00125, say .1 percent, or to about ρ = 1.06

Caution is necessary in the above method, and preferably it should not be used with Element ranges differing more than 100 to 10, although 250 to 10 can be used with extreme caution. With certain Elements now available down to 1 watt full scale this method is usable with medium and low power transmitters.

4. MEASUREMENT & MONITORING OF TRANSMITTER POWER

Little more need be said about this, in view of LOAD POWER paragraph above. The THRULINE is useful for continuous monitoring of transmitter output, and may be found useful in continuous monitoring of reflected power, for instance in checking intermittent antenna or line faults.

Like diode devices generally, the THRULINE indicates the carrier component on amplitude modulation, with very little response to sideband components added by modulation.

5. TESTING OF LINES, CONNECTORS, FILTERS, ETC.

The THRULINE is highly useful for this purpose, and may be employed in several ways.

(a) VSWR (Insertion) or Ø (Insertion) may be measured with the line terminated in a good load resistor (TERMALINE). The lower limits of sensitivity in this are given above under LOW REFLECTION MEASUREMENTS.

(b) ATTENUATION (Power lost by heat in the line) as well as VSWR (Insertion) and Ø (Insertion) may be measured by inserting the unknown line between two THRULINES, or between two RF bodies used with one meter and one set of Elements. (End of line to be terminated in a load resistor). This method applies also to insertion between the THRULINE and a TERMALINE absorption wattmeter.

Very small values of attenuation require allowance for normal instrument errors. The correction may be determined by direct rigid connection of the THRULINES, or of the THRULINE - TERMALINE combination, in cascade. Slight juggling of zero settings is permissible for convenience in eliminating computation, provided readings are being taken fairly well up on scale.

(c) ATTENUATION BY OPEN OR SHORT CIRCUIT METHOD. Neater by far than method (b) is one depending on the high directivity (null balance) to which the THRULINE Elements are held. They should, and do, exhibit good equality between forward and reflected readings when the load connector is open or short circuited. In this condition Ø = 100 percent, the forward and reflected waves being equal in magnitude, and $\rho = \infty$ Say that this is checked on open circuit, and then a length of line of unknown attenuation, also open circuited, is connected to the load connector. The ratio Ø then shown is the attenuation in two passes along the line (down and back).

Expressed in dB, (using the equation $N_{dB} = \log \frac{\overset{F}{W}}{\overset{R}{W}}$),

the dB figure may be compared with published data for line type and length by remembering to halve N_{dB}* because twice the line length is actually being measured.

This measurement should be supplemented by one of Ø (Insertion) as in (a) above, or at least by dc continuity and leakage checks, since the attenuation measurement alone can be in error from faults such as open or short circuits part way down the line.

---

*Or to double the line length.

Open circuit testing is somewhat to be preferred to short circuit, since the reference short (used to check equality initially) must be good, and because the initial equality is somewhat better on open than on short circuit.

Again, for quite low values of measured attenuation, it is advisable to note exact readings (or difference) on the initial equality check, and to allow for this difference.

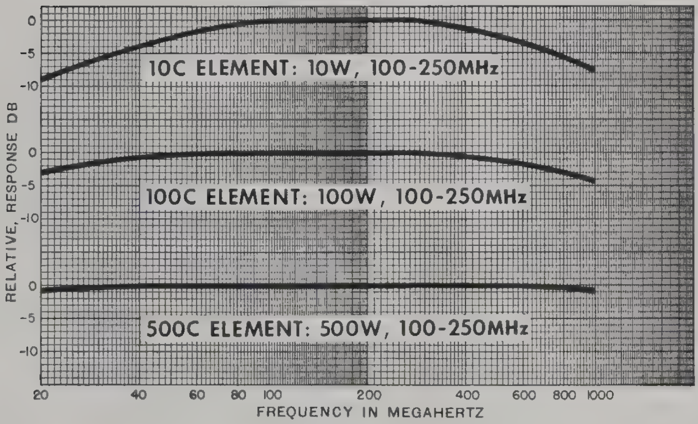
6. FREQUENCY RESPONSE

The Plug-In Elements have a very flat frequency response over a frequency ratio of more than 2-1/2 to one. This characteristic provides a practically flat response within the assigned frequency ranges for all the Elements, see Table I in this Section.

An illustrative set of curves for three Elements of one of these frequency bands is shown in Fig. 4-2. Notice that on the LOW POWER Element, the fall-off above and below the assigned frequency band is more pronounced than it is for the HIGH POWER Element. The degree of drop in response varies progressively less for each power level from low to high, with the average difference at approximately the mean power level. These curves, Fig. 4-2, may be assumed to be about typical for all of the listed band types (H, A, B, C, D & E) at their respective stated frequencies.

Harmonics, or sub-harmonics, may be known to exist in the measured circuit (outside of the Element frequency band). If so, a rough approximation of the response of the Element to these harmonics may be made by the use of these curves. The frequency ordinate to be read on the graph will be obtained by proportioning the frequency of the Element used with that of the one illustrated. Interpolation of the curve values will give an approximation of the extent that these harmonic signals are being measured by your Element.

The use of the Elements for direct power measurements outside of their stated frequency range is not recommended.



FREQUENCY RESPONSE
THRULINE ELEMENTS
100-250 MHz

Fig. 4-2. Graph — Representative Frequency Response

7. IMPEDANCE MISMATCH

There may be cases where it is necessary to use the THRULINE on other than the 50-ohm circuit for which it is designed.

Using the THRULINE, you will be inserting a 4-inch length of 50-ohm air line and the load on the transmitter will be changed from its original condition without the THRULINE. For a power reflection factor under 10% and frequency below 200 MHz, the 4-inch length mismatch is not too serious. But going any higher than these values, even if the transmitter is tuned up with the THRULINE in place, the load impedance will be very different when it is removed.

The THRULINE, of course, indicates zero reflection when the load, at its load connector, is 50 ohms, pure resistive. An ideal condition on a 70-ohm line on the load side of the THRULINE will show 3% reflected power, i.e., THRULINE load is 70 ohms resistive, VSWR in the 50-ohm THRULINE is 70/50 = 1.4. The THRULINE can also show this same reflected percentage with 50/1.4 = 35.7 ohms pure resistive load which could exist with 10% reflected power on the 70-ohm line (VSWR = 2 on the 70-ohm line). From this you can see that the 70-ohm line could have as much as 10% reflected power and VSWR = 2 when the THRULINE indicates 3% reflected power of VSWR = 1.4.

It should be especially remembered that with 70-ohm lines it is most important to get the reflected power indication and subtract it from the forward, because of this factor being so much more critical here than with intended 50-ohm line.

TABLE I — STANDARD ELEMENTS (CAT. NOS.)

TYPE	Freq. Band MHz	WATTS FULL SCALE									
		5	10	25	50	100	250	500	1000	2500	5000
H	2-30	-	-	-	50H	100H	250H	500H	1000H	2500H	5000H
A	25-60	5A	10A	25A	50A	100A	250A	500A	1000A	-	-
B	50-125	5B	10B	25B	50B	100B	250B	500B	1000B	-	-
C	100-250	5C	10C	25C	50C	100C	250C	500C	1000C	-	-
D	200-500	5D	10D	25D	50D	100D	250D	500D	1000D	-	-
E	400-1000	5E	10E	25E	50E	100E	250E	500E	1000E	-	-

In addition to the Standard Types listed above, other special Elements are provided as follows: (See Bird Gen. Catalog)

Table II — Low Power Elements 1 and 2.5 watts in nine narrow band units from 60 to 950 MHz.

Table III — High Frequency Elements 1, 2.5, 5, 10, and 25 watts in four frequency bands; 950-1260 MHz, 1100-1800 MHz, 1700-2200 MHz and 2200-2300 MHz, respectively.

Table IV — Low Frequency Elements 1K, 2.5K, 5K, and 10K watts in one frequency band; .45 to 2.5 MHz.

SPECIAL NOTE

For the convenience of users, a set of VSWR conversion nomographs is appended to this handbook. With these charts, VSWR's may be directly ascertained from forward and reverse power values read from the THRULINE Wattmeter.

SECTION 5
MAINTENANCE

1. INTRODUCTION

With the simple construction and generally self-contained nature of the THRULINE equipment, there is only a moderate amount of maintenance required. One of the major precautions is in handling; use reasonable care and do not drop the THRULINE equipment or the Plug-In Elements.

The main factor in maintenance is care and cleanliness. The Element socket should be kept plugged as much as possible to prevent the intrusion of dust. When a Plug-In Element is used for this purpose (use highest power Element available), it should be positioned with the ARROW pointing upwards. This protects the meter and will not expose the Element crystal to dangerous potentials if the RF line section should be energized. If any of the contacts or line connectors become dirty, they should be cleaned with a little dry cleaning solvent, Inhibisol* or its equivalent, or trichlorethylene, on a cotton swab stick. Avoid excessive skin contact or inhalation of fumes when using. Observe special care if carbon tetrachloride is used. Clean all contact areas and especially the exposed faces of the Teflon* insulators.

It is particularly important to keep the mating surfaces of the socket and Plug-In Element clean. This applies to the bore of the socket and the circumference of the THRULINE Element body, but most important to the bottom rim of the Element body and the seat at the base of the socket in the line section. Also, check the ends of the insulated dc contacts on the THRULINE Element to see that they are clean and smooth. These parts should be carefully cleaned with a cotton swab stick and dry cleaning solvent, as above. There must be a good contact between the base of the Plug-In Element and its socket to assure stable operation of the THRULINE.

In cleaning the socket bore, the operator should be careful not to disturb the spring finger of the dc contact. It is important that the operating position of this part be properly maintained. If the spring finger of the dc contact requires adjustment, it may be done manually if carried out with care. The button must be positioned far enough out to maintain good contact with the Element, but not so as to interfere with easy entry of the Element body. The dc jack (with spring finger) may be removed for access by unscrewing the two #4-40 fillister head machine screws which fasten it to the side of the RF line section. Then retract its assembly, watching carefully not to lose the small teflon positioning bead that straddles the base of the phosphor bronze spring and nests in a counterbore on the side of the RF body. When replacing the assembly, be sure that the bead is again properly inserted.

If there is any evidence of the contamination inside the RF line section, the reachable portions should be likewise wiped and the interior carefully blown out. Under no circumstances attempt to remove the RF center conductor. It is tightly frozen in place and any attempt to remove it will ruin the assembly. Keep all connections tight, and keep the nut of the meter cord plug turned tight on the line section dc jack. This connection may often be serviced by simply loosening the nut of the dc plug, swinging the body several times through a fraction of a turn, and retightening the knurled nut securely.

There are no replacement parts furnished with this equipment. As previously mentioned, components of these matched units cannot be interchanged or individually replaced. The replaceable portions to the Line Section are standard parts of the coaxial line fastenings.

2. TROUBLE SHOOTING

As a brief guide to the operator in isolating occasional difficulties that may occur in the use of the THRULINE, the following summary is included. The remedies for same are referenced to the text in this section or are self-evident:

DIFFICULTY	POSSIBLE CAUSES
No Meter Indication	No radio frequency power. Arrow on Plug-In Element pointing wrong direction. No pick-up from dc contact finger in the RF line section — adjust per Paragraph 1. Open or short circuit in dc meter cable — replace defective cable (RG-58/U) Meter burned out or damaged.
Intermittent or inconsistent meter readings.	Faulty load. Faulty transmission line. Dirty dc contacts on Elements — Clean as in Paragraph 1. Sticky or defective meter.
High VSWR or high percent reflected power.	Bad load, or poor connectors — see Paragraph 1. Shorted or open transmission line. Foreign material in line section or in RF connector bodies — See Paragraph 1.

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3. CALIBRATION CHECKS—THRULINE VS. TERMALINE WATTMETERS

It is recognized that calibration of absorption wattmeters is difficult and likely to be inaccurate unless comparison is made with a transmission (through) type of standard. The THRULINE being of such type, a natural question is: can a THRULINE be used to check or recalibrate absorption wattmeters, such as the Bird Electronic TERMALINE, both being rated at ±5 percent accuracy? The main question is one of exact power calibration.

The answer is a qualified yes, although with both instruments being about equally old and known to be undamaged, there is not too much reason to prefer either on probable accuracy. The edge is somewhat in favor of the THRULINE, because each Element covers only 2-1/2 to 1 in frequency and will be flatter originally over this range than the TERMALINE can be held initially over its very much wider (16.7 to 1) frequency range. Also the THRULINE will probably exhibit smaller changes with time, because of the narrower frequency range, because it is simpler in general design and easier in function (does not have to serve as a power load), and because it does not become heated in operation.

Certainly if the absorption wattmeter has gone years since calibration, or is reasonably suspected of inaccuracy, it may well be calibrated against the THRULINE as standard. (Rather than use correction factors, one can, with the TERMALINE Wattmeter, make use of the calibration adjustment screws used in factory calibration. These are concealed and not mentioned in instruction book to discourage tampering. Correspondence is necessary.)

If such calibration is undertaken, care and thoroughness are advised.

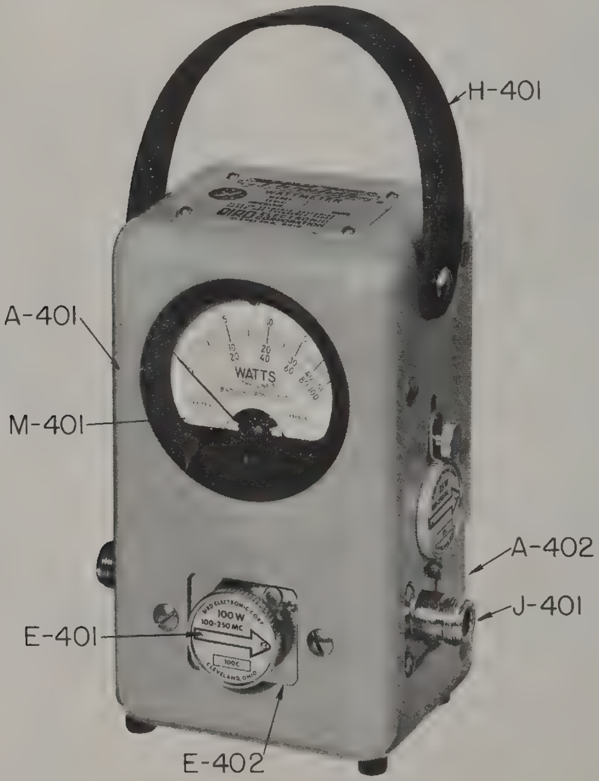


Fig. 5-1. Parts Illustration.

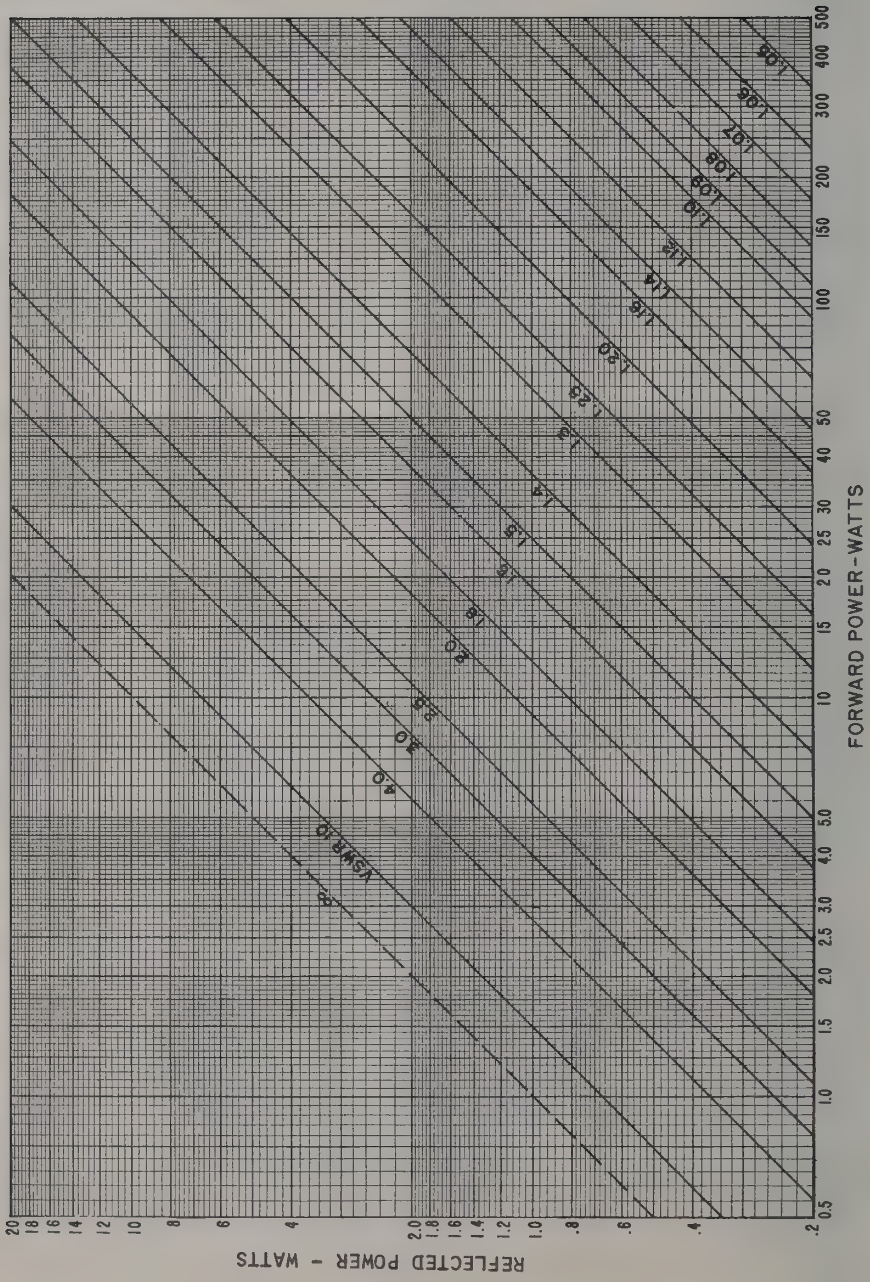
SECTION 6 - PARTS LIST

Reference Designation	Part Name and Description	Function	Drawing No.
A-401	Housing Assembly: Aluminum die casting, 7 lg x 4w x 3h, w/latch and thumbscrew each side for spare Elements, four rubber bumpers on base, leather carrying strap at top. Gray Enamel.	Houses and protects meter, holds RF line section and spare Element.	4210-018
A-402	Cover Assembly: Aluminum alloy sheet, .040 thk., 6-1/2 lg x 4w x 1-1/2h overall, has four rubber bumpers and slot closing ears. Gray Enamel.	Closes back of housing.	4210-005
E-401	Elements, Plug-In: Brass, w/teflon bottom cover, 1-7/16 lg x 1-1/4 cap dia. x 1 body dia. Gold Plate. Furnished in power and frequency types per Table I, Section 4.	Measuring Element for THRULINE.	4250-020
E-402	Line Section Assembly: Brass Casting, normally supplied w/two female "N" connectors, 5-1/8 lg x 1-1/4w x 1-15/16h, 50-ohm line section and socket for Plug-In Element. Has dc jack at side. Nickel Plate.	RF Line insertion section and measuring base.	4230-018
H-401	Carry Strap: Black Leather, 9 lg between centers, 5/32 x 7/8 section.	Carries meter housing.	8580-003
J-400	Connectors, RF: All types have 1-1/4 sq. mtg. flange, and 1/8 dia. x 5/16 lg. slotted connector pin at rear. Brass, with Teflon insulator. Nickel plate. Fifteen types, viz:	RF connection for standard type connectors.	See individual part numbers listed below.
J-401	Female "N" - 1-5/32 lg.		4240-062
J-402	Male "N" - 1-1/4 lg.		4240-063
J-403	Female "HN" - 1-5/32 lg.		4240-268
J-404	Male "HN" - 1-3/8 lg.		4240-278
J-405	Female "C" - 1-1/16 lg.		4240-100
J-406	Male "C" - 1-7/16 lg.		4240-110
J-407	Female UHF (SO-239) 1-1/4 lg.		4240-050
J-408	Male UHF (PL-259) 1-5/8 lg.		4240-179
J-409	Female "BNC" - 1-5/32 lg.		4240-125
J-410	Male "BNC" - 1-9/32 lg.		4240-132
J-413	Female "LC" - 2-1/32 lg.		4240-031
J-414	Male "LC" - 2-1/2 lg.		4240-025
J-415	Female "LT" - 2-3/32 lg.		4240-018
J-416	Male "LT" - 2-1/2 lg.		4240-012
J-417	7/8" EIA Air Line 2-3/4 lg.		4240-002
J-411	DC Connector Assembly: Brass fitting, w/phosphor bronze spring at rear, 1"dia. flange x 1-1/4 overall, 5/8 -24 thd. on connector body, center contact on front, teflon insulators. Nickel Plate.	DC Jack for line section assembly.	4230-010
M-401	Microammeter: 30ua full scale. Flush 3-1/2" bakelite case, solder terminals, special scale.	Meter for power reading. (For replacement usually furnished as 8-000 Kit.	2080-002
	Replacement Meter Kit Consisting of: 1 - 2080-002 Meter 1 - 4220-097-1 Cable Assembly 3 - 4220-098 Bumper Feet		8-000
P-401	Connector, Plug: Part of cable W-403, Brass fitting 1-1/4 lg x 5/8h x 3/4d, water proof. Nickel Plate. Navy type DS-491859.	DC Plug for RG-58/U meter cord.	7500-076
W-403	Meter Cable Assembly: RG-58/U cable, 2-3/4 feet long, w/dc plug P-401 at one end.	Meter Cord.	4220-097-1

APPENDIX

HIGHER RATIOS

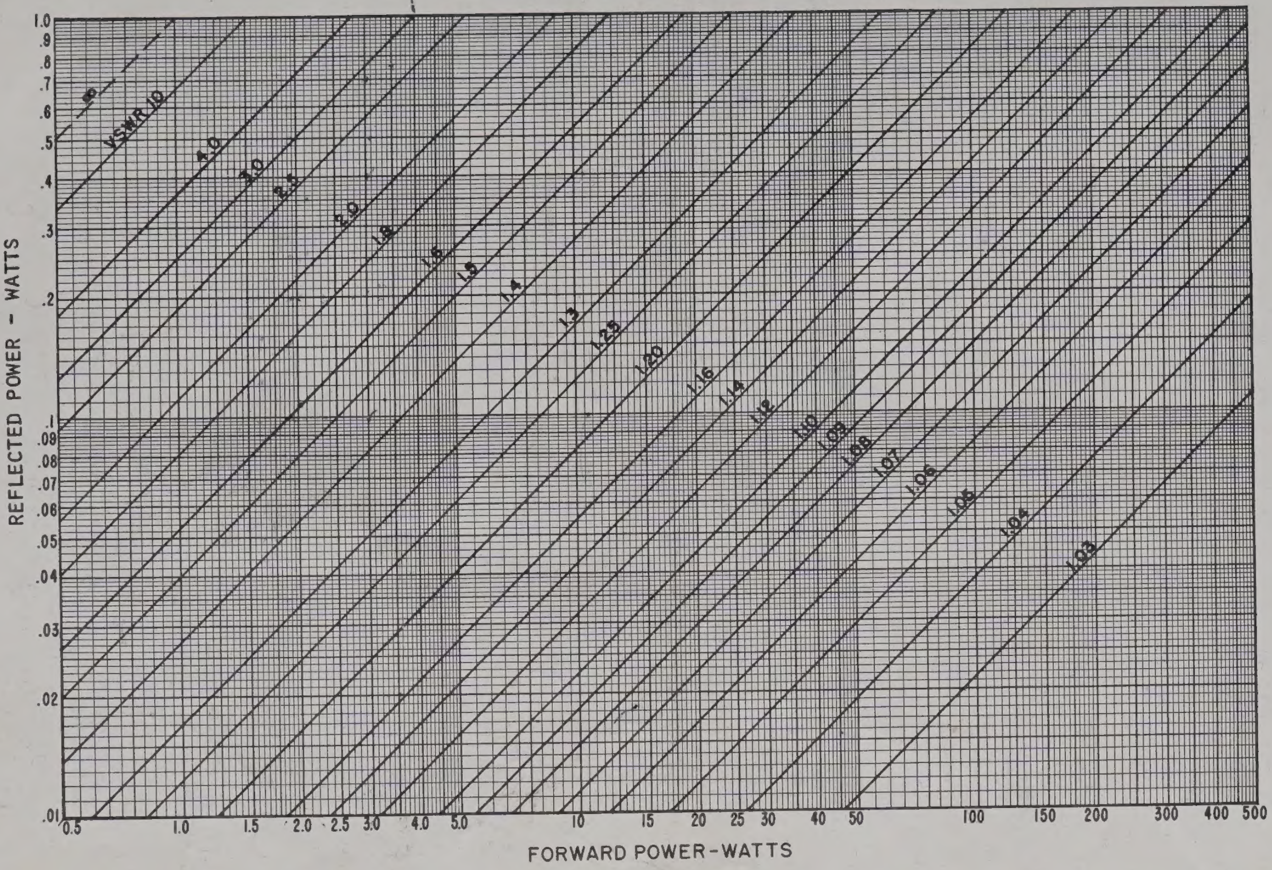
POWER VALUES vs. VSWR



APPENDIX

LOWER RATIOS

POWER VALUES vs. VSWR



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